NASA/CR—2002-211903

NASA Aviation Safety Program Weather Accident Prevention/Weather Information Communications (WINCOMM)

Arthur Feinberg and James Tauss
Aviation Management Associates, Inc., Springfield, Virginia

October 2002

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Prepared under Contract C–77109–T

National Aeronautics and
Space Administration

Glenn Research Center

October 2002

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Executive Summary

Weather is a contributing factor in approximately 25-30% of general aviation accidents. The lack of timely, accurate and useable weather information to the general aviation pilot in the cockpit to enhance pilot situational awareness and improve pilot judgment remains a major impediment to improving aviation safety.

NASA Glenn Research Center (GRC) commissioned this 120 day weather datalink market survey to assess the technologies, infrastructure, products and services of commercial avionics systems being marketed to the general aviation community to address these longstanding safety concerns.

A market survey of companies providing or proposing to provide graphical weather information to the general aviation cockpit was conducted. Fifteen commercial companies were surveyed. These systems are characterized and evaluated in this report by availability, end-user pricing/cost, system constraints/limits and technical specifications. An analysis of market survey results and an evaluation of product offerings were made. In addition, recommendations to NASA for additional research and technology development investment have been made as a result of this survey to accelerate deployment of cockpit weather information systems for enhancing aviation safety.

A methodology for this market survey was initially established. Survey forms were prepared to insure consistent questions were asked of each vendor and appropriate information obtained.

Aviation Management Associates traveled to the annual Sun & Fun Air Show in Lakeland, Florida and the AOPA Fly-In at Frederick, Maryland to meet with vendors and General Aviation (GA) operators.

Aviation Management also contacted aviation associations and others such as AOPA and NBAA, FAA, NASA Centers, MITRE and related industry groups. Additional meetings and phone conversations with commercial vendors were conducted to complete this market survey, assessment and recommendations.

The market survey confirmed that the number of GA operators currently using graphical weather products in the cockpit is small. Further, the commercial products being marketed are new and as yet have unsubstantiated marketing claims. It was concluded that graphical weather data links will achieve greater GA market acceptance as costs continue to decline. GA graphical weather data requirements, however, need to be better defined and standardized to maximize value to the GA user.

It is recommended that NASA conduct an R&D flight test and evaluation of representative commercial weather data link systems. Actual in-flight performance needs to be evaluated and measured against claims of usefulness and performance. It also appears there is a need for NASA to continue its research and development in optimizing weather data links based upon GA pilot weather requirements (both strategic and tactical) and validated through an in-flight evaluation program.

Additional recommendations for future NASA R&D efforts include investigating the utilization of the VHF VDL-3 data link and satellite digital radio service providers for providing graphical weather information to the GA cockpit. NASA should also participate with RTCA committees and the FAA in the Safe Flight 21 program including UAT data link evaluation. Test and evaluation of a hybrid satellite and ground-based weather data link architecture is a candidate for future NASA research and development as well.

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Objective

Background

General Aviation (GA) airplanes and operations encompass a wide range of aircraft types and applications. GA airplanes are operated in support of business and recreation, as well as everything from emergency medical evacuations to border patrols and fire fighting.

They are also used by individuals, companies, state governments, universities and other interests to quickly and efficiently reach the more than 5,000 small and rural communities in the United States that are not served by commercial airlines.

GA is the backbone of the nation's air transportation system and can be a primary training ground for the commercial airline industry. It is also an industry that contributes positively to the nation's economy. GA aircraft range from small, single-engine planes to mid-sized turboprops to the larger turbofans capable of flying non-stop from New York to Tokyo.

Improved safety of flight is critical for continued growth in this arena. In 1997, President Clinton called for an 80% reduction in the rate of fatal accidents by 2007 and a 90% reduction by 2017. In response to this goal, the National Aeronautics and Space Administration (NASA) Aeronautics Safety Investment Strategy Team (ASIST) defined technical objectives for an Aviation Safety Program (AvSP).

The AvSP, in partnership with industry and other Government agencies such as the Federal Aviation Administration (FAA), recognized that weather was a major contributor or factor in aviation incidents and accidents. This has been corroborated in several studies, such as FAA Safer Skies: Focused Safety Agenda [1], and others conducted by the National Transportation Safety Board (NTSB) [2], Aircraft Operators and Pilots Association (AOPA)[3], that concluded a significant percentage of delays, accidents, and fatalities incurred by GA aircraft are due to weather. For the period 1993 through 2000 weather was a direct cause or factor in approximately 24% of total GA accidents and approximately 30% of total GA fatalities (Table 1).

Table 1: NTSB GA Weather Accident Statistics, 1993-2000

GA Accident Statistics 1993-2000								
Total Accidents								
1993	**1994**	**1995**	**1996**	**1997**	**1998**	**1999**	**2000**	**Total**
24%	21%	25%	28%	25%	24%	25%	21%	24%
Fatal Accidents								
1993	**1994**	**1995**	**1996**	**1997**	**1998**	**1999**	**2000**	**Total**
32%	28%	33%	36%	32%	33%	24%	24%	30%

By building on the FAA's National Airspace System (NAS) modernization plan, GA manufacturers have been busy developing new products that are anticipated to dramatically increase safety and efficiency of the current aviation system. Of all the future technologies that await the GA community, it is envisioned that the availability of improved weather information, such as textual and graphical products and forecasts, could provide the greatest safety benefit.

To achieve these benefits it is important to understand when, where, and for what purpose weather information is needed.

According to the FAA Office of System Safety, an analysis of the Aviation Safety Reporting System 2001 database revealed that the majority of incidents occurred in the en route or descent phase of flight. During these phases of flight there are numerous operational decisions made by the GA pilot as a result of weather. These include in-flight altitude, route or destination changes, as well as decisions affecting approach and landing. Changes in aircraft configuration and performance can also be driven by weather conditions.

According to the FAA's Mission Need Statement for Aviation Weather, 2002 [4] and the FAA's Concept of Use for Weather, Draft 2002 [5], that link weather phenomena to specific operational decisions, weather plays a preeminent role in pilots' operational decisions in both a pre-flight and in-flight environment.

For example, icing, volcanic ash, non-convective turbulence, and cloud top information affects decisions for pre-flight route, or altitude. Unanticipated convective activity or convective activity that develops or moves faster or slower than forecasted can affect GA in-flight operational decisions (Figure 1). Approach and runway selection and are based on acceptable approach procedures that can be affected by cloud base conditions, visibility, crosswind component, and minimums both prior to flight as well as immediately prior to transitioning from the en route to arrival phase of flight.

Figure 1 : Convective activity affects all GA decisions

Thus, the need for pre-flight and in-flight weather information to assist in making good operational decisions appears obvious. To make this a reality weather information collection, processing and dissemination systems must be in place and consistently perform with the highest levels of accuracy, availability, timeliness, reliability, and integrity.

The recent development and deployment of in-flight airborne weather systems demand that weather information providers, methods for up-linking data, and cockpit displays must meet these same high levels of system performance as required for traditional pre-flight systems.

NASA's Weather Accident Prevention (WxAP) project under AvSP was formed to achieve several objectives to assist in the development of in-flight weather capabilities:

- Develop technologies to provide information to aviation decision-makers such as pilots, dispatch, and ATC. The Aviation Weather Information (AWIN) program was formed to address this objective.

- Develop standardized communication technologies to meet the first objective. The Weather Information Communications (WINCOMM) program was formed to address this objective.

- Provide on-board turbulence sensors for advanced warning.

- Define flight management systems to reduce effects of turbulence. The Turbulence Detection and Mitigation research programs were formed to address these two objectives.

The AWIN program element, centered at NASA Langley, performs research and development geared to decreasing accidents by improving weather information available to aviation users. The program is focused on human factors issues including the development of technologies that will lead to improved design and use of improved cockpit weather information via graphical displays of data linked weather products.

However, as good as the weather graphics may be, they are of no use to the GA pilot unless the information can make the trip to the cockpit. In this regard, the WINCOMM program element, centered at the Glen Research Center (GRC) in Cleveland, is geared towards the development of emerging communication technologies and supporting standards definitions, needed to satisfy weather informational needs in the cockpit.

How information reaches the cockpit is called data link and refers to the communication transmission between a service provider and the aviation cockpit while in-flight. Current techniques include ground-based and satellite-based architectures.

Ground-based architectures range from a nationwide cellular network using existing telecommunications tower infrastructures, to very high frequency (VHF) broadcast network using FAA provided spectrum, and a VHF network using the Aircraft Communications and Reporting System (ACARS) existing infrastructure.

Satellite-based architectures currently leverage Low Earth Orbiting (LEO) constellation networks. Planned architectures will use the Geosynchronous Earth Orbiting (GEO) satellite for broadcast dissemination of weather information.

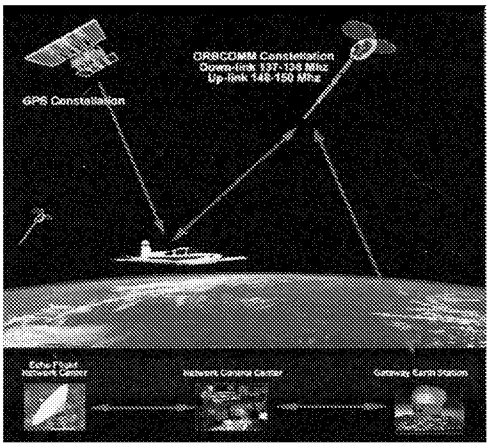


Figure 2: Example of LEO data link architecture as implemented by Echo Flight

How well these architectures perform in bringing timely weather graphics to the cockpit and what future data link technologies will be marketable to GA users is a topic of some debate.

For data link in particular, the constraints of bandwidth, sometimes expressed as a function of how fast data transmissions take place, capacity (the ability to add products), and coverage (the ability to receive information when and where it is needed), are major factors. Weather graphics can contain large amounts of data which make for huge file sizes and slow data transmission rates. The information is often quite perishable meaning that its value to the pilot for decision making diminishes with time.

With these constraints in mind, strategies for getting graphical weather products to the cockpit are still evolving. Of particular importance to the WINCOMM program is:

- Information Throughput: This refers to emerging communication technologies that will be able to improve delivery rate of weather information to the cockpit.

- Communications System Capacity: This refers to the development of technologies to enable anticipated communication system capacity.

- User Connectivity: This refers to an improvement in coverage and access to weather information in the cockpit.

Objectives in the Statement of Work

Commercial avionic systems are being marketed to the GA community to address aviation safety and efficiency of flight concerns.

The NASA WINCOMM group has a critical interest in the availability and potential effectiveness of these commercial offerings in bringing graphical weather information to the cockpit to address GA pilot weather needs.

An assessment of data link technologies, infrastructure, and proposed weather products and services will facilitate the determination of technological maturity of the industry in order for the WINCOMM program to strategically plan for future research investment decisions.

Products and Services

A market survey of companies currently providing or proposing to provide graphical weather information to the GA cockpit has been performed. The surveyed systems have been evaluated by the following factors:

Availability in the Market:

Several commercial offerings are currently available. This means that avionics can be ordered in the form of a turnkey system and various weather products can be received in the cockpit, usually on a subscription basis. FAA certification has been approved for installed equipment. FAA certification of avionics equipment is important since this ensures that minimum safety and performance standards for aircraft installed systems have been met.

Several commercial offerings are still in the planned or proposed stages. This generally means that strategic partnerships between avionics manufacturers and weather data providers are being formed. Avionics software to receive weather products and/or to transmit requests for products may be in development.

End-user pricing and cost:

Costs to receive weather graphics in the cockpit fall into two categories: Nonrecurring and recurring.

Nonrecurring costs apply to the one-time purchase of avionics equipment and refer to all hardware and software components required to create a turnkey "system" for weather graphics in the cockpit. Nonrecurring costs would also include installation. It is important to realize the costs of all required components of such a system in order to clearly understand what, if any, legacy equipage can be leveraged to display weather products. It is also important to understand what additional functionality can be performed or information displayed along with weather graphics to determine relative value to GA operational decision making over weather graphics alone.

Recurring costs generally refer to those occurring on a regular basis such as a monthly or yearly service or subscription for

graphical weather products. Over the course of a year or two, some service costs may not be trivial. This can occur if the GA pilot does not fly year round and monthly charges continue without product use. Additionally, costs can accumulate quickly if a cost-per-product arrangement has been made and the pilot either flies more often than planned or desires more frequent product updates than anticipated.

Others as Appropriate:

Maintenance and warranty are important for in-service upgrades for both avionics and weather service providers and overall manufacturer product or service liability and repair practices. Compatible functionality and interfacing between avionics manufacturers, suggesting open architecture capability, is important for equipage with legacy avionics and to realize broader acceptance between manufacturers.

System Constraints or Limitations

Aircraft Type:

It is important to realize the specific GA market commercial manufacturers are targeting and the types of GA aircraft that will be compatible with offered avionics hardware and software. This will address whether specific segments of the GA market are not being adequately served.

Electrical Requirements:

It is important to verify that GA aircraft electrical requirements can support offered weather avionics systems.

Mounting and Surface Area:

Physical aircraft mounting limitations for currently available or proposed avionics systems are important for compatibility in the GA cockpit and again, to determine market limitations. This includes panel display, antenna fuselage installations, cockpit controls, and processors.

Others as Appropriate:

It is important to survey all other GA aircraft system physical and electrical constraints to determine other limitations that may restrict market penetration.

Technical Specifications

Weather Data Sources:

A survey of commercial companies providing textual and graphical weather information to the GA cockpit is important to realize the kinds of products currently available and to compare offerings with regard to known or postulated GA weather requirements. This will identify all the major players providing weather data and will serve to determine if product content is congruent with pilot weather needs. Standardization of product and product content is important for collaborative decision making (CDM) or information parity, when applicable, between pilot and controller.

Resolution:

Resolution of weather graphics is important to determine overall weather graphic quality and to determine if all weather features important to the GA pilot can be adequately depicted.

Timeliness:

Timeliness of weather graphics to the cockpit is important. Weather information is perishable – its relative value towards enhancing GA safety diminishes greatly with time. Confidence in the product integrity can also diminish with time since some weather phenomena will have moved from valid time positions towards increasingly unknown positions. Further, with each passing minute the aircraft will have moved relative to the weather phenomena. This may lead to more reactive decision making and a compromise of safety.

Display:

Display characteristics such as brightness, heads up/heads down, clarity, size, colors, etc., generally fall into human factor considerations. However, human factors issues are not within the purview of this study. The displays of avionics vendors will be surveyed and compared but human factors considerations are addressed in other NASA initiatives.

Delivery:

The focus of this study is to survey and evaluate the methods used to data link weather graphics to the GA cockpit. As mentioned in the background section, various delivery architectures have emerged based on perceived GA weather product needs, technological abilities, strategic partnerships, market profiles and related business models for anticipated market penetration. It is important to understand advantages and disadvantages that each delivery architecture brings with regard to product, service, and technical metrics previously outlined as well as any technological constraints that may be preventing or hindering further market penetration.

Others as appropriate:

A survey of other technical specifications as appropriate will be performed to provide further technical understanding of commercial weather data link systems and services to make research investment recommendations to enhance GA safety. For example, product offerings will be evaluated in terms of expected or planned future technology trends and developments that could potentially benefit from additional research and development investments to accelerate deployment of cockpit weather information systems.

Methodology

There are three goals to this study. The first is to identify and survey commercial vendors and weather graphics service providers who currently provide or are planning to provide graphical weather to the GA cockpit. The second is to assess the maturity of the market with respect to various criteria such as data link technology, available avionics, cost, weather products, etc., towards the ability to satisfy GA weather needs and improve safety of flight. The third is to identify areas that could benefit from additional research and development technology investment.

Information Gathering Methodology

Identification of commercial vendors and users of graphical weather avionics was conducted by several methods including in-house knowledge, Internet searches, and interfacing with Government organizations (FAA, NASA). Also, reviews of professional publications (Aviation Week and Space Technology, Avionics, AOPA Pilot Magazine, Avionics News (AEA), etc.) were accomplished. In addition, professional organizations including Aircraft Electronics Association (AEA), Experimental Aircraft Association (EAA), National Business Aircraft Association (NBAA), General Aviation Manufacturers Association (GAMA), Aircraft Owners and Pilots Association, etc) were contacted. Meeting were also held with GA user groups (AOPA, NBAA, GAMA, AEA, etc.), and at GA user shows and conferences (Sun N Fun, AOPA Fly-in, etc).

The focus here was to identify the major players who had current capability to bring graphical weather to the cockpit or who had seemingly realistic plans to do so in the near future.

Identification of users was made through direct pilot contacts, vendor contacts, and avionics dealer lists.

The results of the identification task revealed that 15 commercial vendors had current or planned capabilities. These are:

- Aircell, Inc.
- ARNAV
- Avidyne
- ControlVision
- Echo Flight
- Flytimer
- Garmin
- Goodrich
- Honeywell Bendix/King.
- Jeppesen
- Rockwell Collins
- Satellite Technologies, Inc.
- Universal Avionics
- UPS Aviation
- WSI Corp.

With 15 major vendors comprising the marketplace, an interview-style approach as opposed to a mass mailing was used to conduct the survey. Further, due the available time to perform the survey, one major decision-maker from each company was identified to participate in the survey such as President/CEO, Lead Business Developer, GA Avionics Program Manager, etc.

Before the survey could be developed, it was essential to determine the intended use of the data towards addressing goals two and three, and to build into the design survey features such as focus and question type necessary to allow use in that way (Sonquist and Dunkelberg, 1977 [6]. Further, the most informative comparisons between different organizations working towards similar market goals can be revealed when the questions are standardized and highly focused. Finally, length of the survey was considered. Higher participant interest was envisioned if the questions were kept fairly short and to the point with overall question numbers kept reasonably low. This was especially valid for the user survey.

The information gathering methodology, shown in Figure 3, began with the development of questions derived from various sources to elicit answers that would satisfy study goals. These sources included knowledge of GA graphical weather needs, knowledge of data link communication architectures and protocols, study SOW requirements or goals, and perceptions from NASA.

GA graphical weather needs have been described in various sources such as the General Aviation Users' Forum, 1993 [7], National Aviation Weather Users' Forum, 1999[8], Mission Need Statement for Aviation Weather, #339, 2002, "Concept of Use for Weather", 2002, as well as various other professional papers as referenced in Appendix 3. These references were used as guidance for weather product question development and overall background weather knowledge.

In-house knowledge of the SOW issues of interest were used to develop question type sections. These included background in the operational use of GA avionics, operational GA use of weather information, communication data link history and technical issues, and product installation, integration, and certification issues.

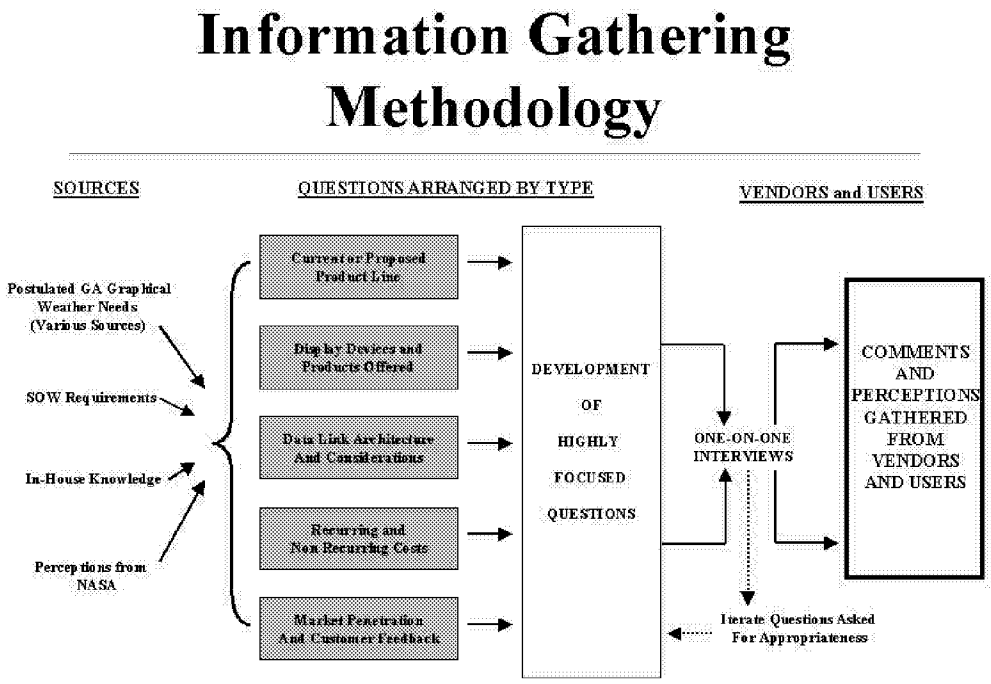


Figure 3: Information Gathering Methodology

An additional source of input was perceptions provided from NASA including perceived level of product or service maturity and real in-service experiences with weather graphics vs. advertised capability. Survey questions were developed to validate or dispel these perceptions.

Questions were arranged by type including the broad categories:

- Current or proposed product type (name, description, H/W or S/W, transceiver, etc)
- Display devices such as Multi-Functional Display, lap-top, etc., and weather products offered such as radar and other graphics, text messages, etc.
- Data link architectures such as Cellular, VHF, satellite, etc., and considerations such as line of site issues, availability, etc.
- Recurring and nonrecurring costs.
- Market penetration and customer feedback from vendor provided sales and user survey comments.

This led to the development of two sets of highly focused questions; one applicable for the commercial vendor, and one for the user. The questions were designed to be open-ended or qualitative and not requiring yes or no answers. Questions that would tend to lead to proprietary-type answers were avoided. Each of these final survey forms is shown in the appendices.

Individual interviews were conducted with identified decision-makers. In many cases the person surveyed was able to review the questions beforehand. Most interviews were conducted in person while others were conducted on the phone. The questions were asked in an unbiased manner. Commercial vendors provided brochures and marketing materials describing avionics and graphical weather services. In some instances a review of the answers and accompanying brochures required follow-up questions to clarify the provided information. The vast majority of the commercial vendors were quite cooperative in participating in the survey.

Survey responses resulted in company facts, avionics product listing, graphical weather products and capability, cost and sales information. In addition, data link architecture and understood constraints, strategic partnerships, current focus including types of GA customers or aircraft and/or planned direction(s), opinions and attitudes regarding perceived market desires, expected (vendor provided) and actual (user provided) operational performance or experiences, and recommended Government initiatives for improved market penetration were also provided.

Information Analysis Methodology

An information analysis methodology was developed to summarize and distill the raw comments received from vendors and users (Figure 4). In order to determine technological constraints experienced by the vendors, a methodology was developed to compare system, service, and product offerings based on the data link architectures.

For example, it was envisioned that technological issues would be data link specific. Therefore, commercial vendors using like data link technologies were compared and contrasted against each other. Comparison of data link architectures in this way translates the information into quantified assessments of the data link maturity with regard to graphical weather products. From this assessment, recommendations for improved data link technologies can be made.

Information Analysis Methodology

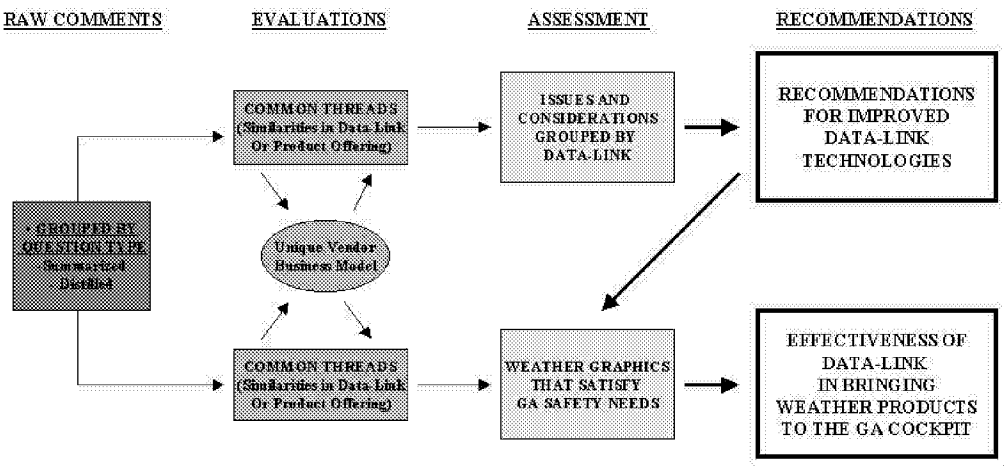


Figure 4:Information Analysis Methodology

Vendor Descriptions–Marketing Highlights

The following section highlights each of the 15 surveyed commercial vendors from a marketing perspective and is not intended to serve as a detailed comparison. Such comparisons can be found in the Analysis section and the matrix table in the Appendix.

A "high-level" comparison matrix has also been included as an appendix to introduce the reader to the more salient considerations.

These vendor descriptions are, intended to introduce the reader to the companies who are currently providing or planning to provide graphical weather products to the cockpit.

The following company provided information is included:

- Company name, address, phone, and point of contact for business development or technical management.
- Products that bring graphical weather to the cockpit, their availability and data link architecture.
- A selection of features, including costs, emphasized in various marketing brochures and/or sales and technical literature. NOTE: Costs do not generally include installation unless otherwise noted.
- Photographs or diagrams of the product or data link architecture.
- A selection of considerations, both positive and negative, described either in the marketing literature or during the interview process with identified points of contact.

There are four major commercial vendors providing graphical weather data to the high-end GA market. These are Honeywell, Rockwell Collins, Teledyne, and Universal Avionics. Because the main focus of this market analysis was towards the pleasure and occasional, or low-end, GA user, commercial vendors targeting this market are only partially illustrated here and in the analysis.

Surveyed Commercial Vendors

- Aircell Inc
- ARNAV
- Avidyne
- ControlVision
- Echo Flight
- Flytimer
- Garmin
- Goodrich
- Honeywell Bendix/King
- Jeppesen
- Rockwell Collins
- Satellite Technologies, Inc
- Universal Avionics
- UPS Aviation
- Weather Services International

AirCell, Inc.
1172 Century Drive, Suite 280
Building B
Louisville, Colorado 80027
(303) 379-0200
www.aircell.com

POC: Brian Cox, Director of New Technology
(303) 379-0239, Fax (303) 379-0201
bcox@aircell.com

Product:

- **Guardian 1000 transceiver@$3,500**
- **DataComm 500 Transceiver @$2,000**
- **AT.02 Transceiver @$4,000**
- **AGT.02 Transceiver @$8,000**

Availability:

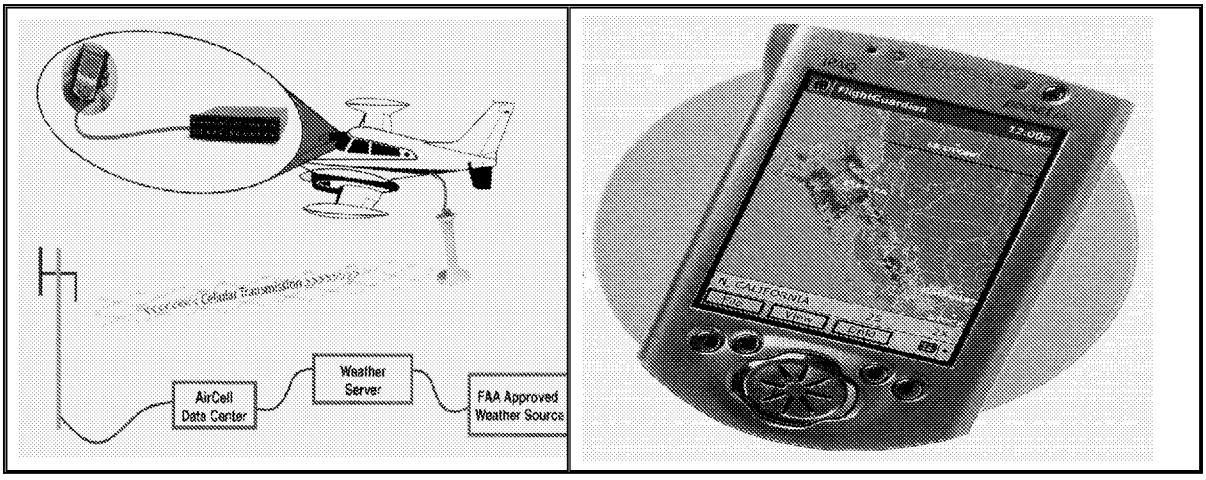
- **All current except for DataComm 500**

Weather Data Link:

- **Ground-based Cellular Network**
- **Weather provider is Meteorologix**

Features:

- **Voice and Data/Graphics in air**
- **FAA-approved in-flight cellular telephone**
- **Dual certification: Up to 250kts for Guardian; Up to 600kts for AT.02**
- **Flight Guardian S/W displays NEXRAD images on MFD's, EFB's, and PDA's**
- **Several rate plans from $9.95/month to $499.95/month depending on service (voice or data alone) and included minutes**
- **1 and 2 year limited warranty**



Considerations:

- **Line of site constraints; Typically starts above 5K AGL**
- **Only pay for link when data transmitting (R/R by the minute)**
- **Flexibility to add more channels**
- **20-25kbyte files download in about a minute**
- **16 levels of reflectivity for NEXRAD products; 2km resolution**

ARNAV

Pierce County Airport
16923 Meridian East
Puyallup, WA 98373
(253) 848-6060
www.arnav.com

POC: Susan M. Hamner, Vice President,
Radio Navigation Flight Electronics
Wireless Communications
(253) 848-6060 x28, FAX (253) 848-3555
shamner@arnav.com

Product:

- **Wx Link is a multi-mode, multi-frequency weather broadcast data link portion of the ARNAV Aeronautical Network (AAN)**
- **DR-100 receiver/antenna@$1,495**
- **SatPhone transceiver@$19,995**
- **MFD 5200 display@$6,000**
- **MFD ICDS display@$8,000**

Availability:

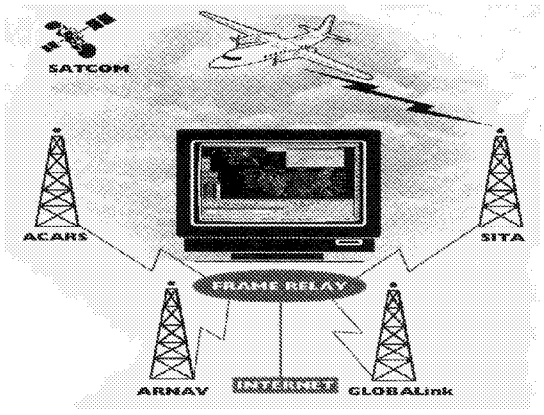
- **Satellite data link current; ARNAV network limited availability, FISDL not available**

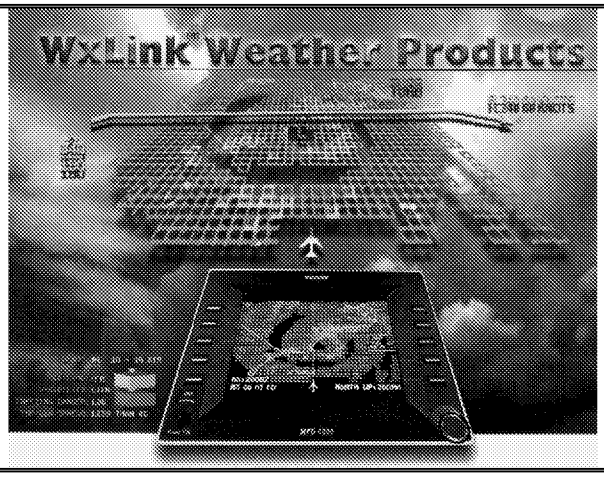
Weather Data Link:

- **LEO Satellite**
- **VHF GMSK ground-based digital broadcast**
- **Weather provider is Meteorologix**

Features:

- **Voice and data via satellite; R/R**
- **FAA certified products**
- **Free weather text via FAA provided spectrum**
- **Premium weather graphics @ $495/year**
- **VHF ground-based network uses a periodic broadcast technique; Plan to convert to VDL-Mode2 in 2004**
- **DR-100 receiver is compatible with several other manufacturer MFD's**





Considerations:

- **Currently implementing VHF GMSK**
- **FAA and ARNAV not making any public statements on FISDL deployment; Web site indicates limited availability of weather products over ARNAV proprietary network only**
- **4 levels of reflectivity on NEXRAD products; 64km resolution nationally, 8km resolution regionally**

Avidyne Corp.
55 Old Bedford Road
Lincoln, MA 01773
(800) 284 3963
www.avidyne.com
POC: Jason Och, Product Manager New Business Development
(781) 402 7476
joch@avidyne.com

Product:

- **FlightMax DX50 transceiver @ $2,950**
- **Weather graphics can be shown on all FlightMax MFD's which range in price from the 850 series @ $17,950 to the 450 series @ $9,950**

Availability:

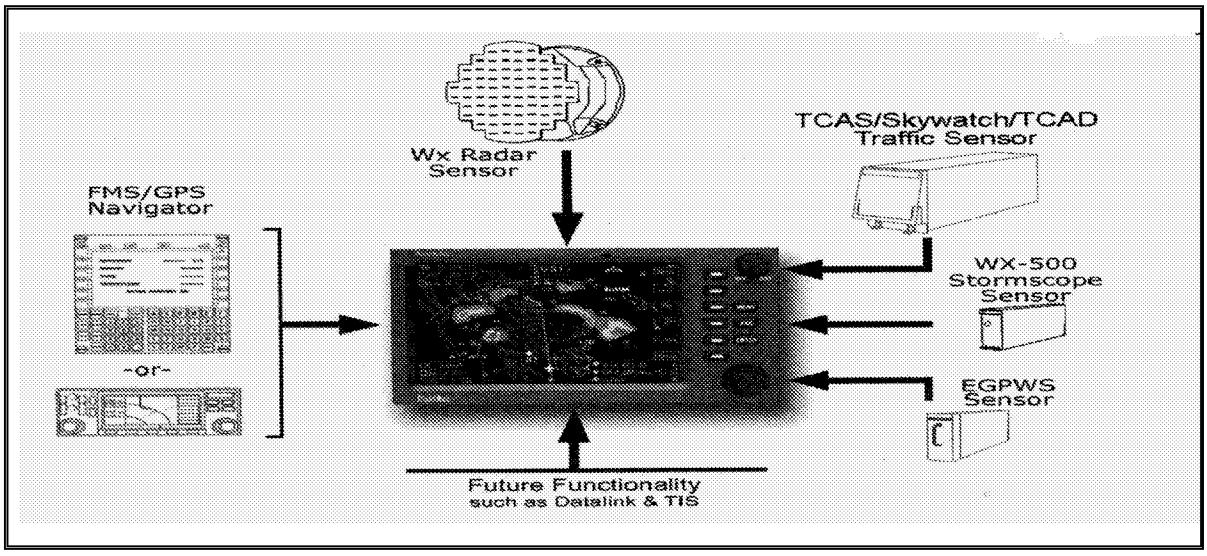
- **DX50 availability planned mid-late 2002**

Weather Data Link:

- **LEO satellite**
- **Weather provider TBD**

Features:

- **Bi-directional R/R via satellite**
- **All-altitude, CONUS data link coverage**
- **MFD can be stand-alone, mounted remotely, and VHF compatible**
- **Combination transceiver can interface with several technologies (i.e., GPS flight plan functionality, traffic, terrain, etc)**
- **$599/year (30 updates/month) or $349/year (10 updates/month) planned pricing**
- **2-7 minutes typical response time**



Considerations:

- **Data only**
- **Weather provider not announced yet**
- **DX50 designed to interface only with FlightMax systems**
- **FAA certification planned**
- **Geared towards higher-end GA users**

ControlVision

Box 596
Pittsburgh, KS 66762
(800) 292 1160
www.anywheremap.com

POC: Richard Herbst, Marketing Manager
(620) 231 6647
richard@anywheremap.com

Product:

- **Anywhere Wx integrated GPS flight manager S/W @ $2,899 introductory package (inc. S/W, GlobalStar Phone, GPS receiver, PDA display, power pack, and Yoke Mount)**
- **Anywhere Wx with Aircell interface @ $1,295 ($1,995 with PDA but no other Aircell equipment included)**

Availability:

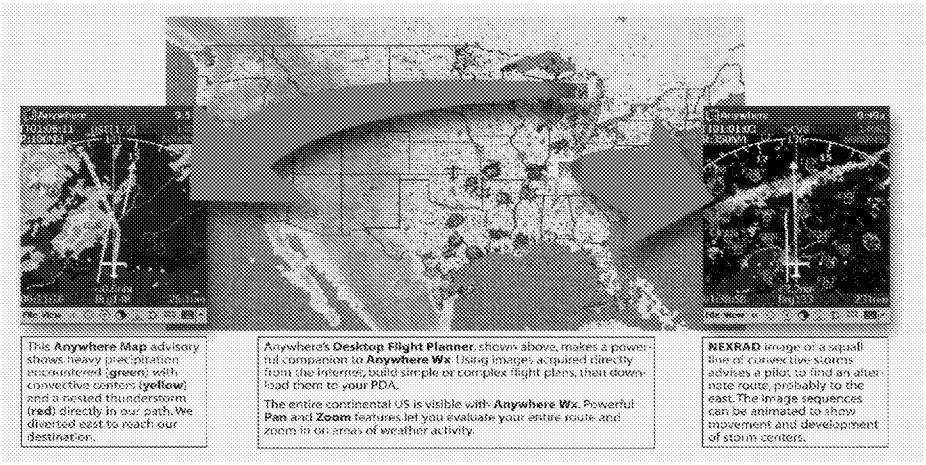
- **Current**

Weather Data Link:

- **LEO satellite**
- **Ground-based cellular network (Aircell)**
- **Weather provider is Meteorologix**

Features:

- **Satellite R/R data link service; Ground-based network data and voice**
- **Aircraft phone serves as a dialer and modem**
- **$30-110/month plus $1.49-1.69/minute for weather products; Rates dictated by number of free plan minutes**
- **6 months of free upgrades then $115/year for 12 upgrades**
- **6 month limited warranty for H/W**
- **Proprietary compression allows for NEXRAD display and METARS to be available in less than 1 minute from request**



Considerations:

- **Need Aircell Guardian transceiver @ $3,500 for Aircell service**
- **Communications line is dropped after 1 minute, Not IFR certified**
- **Need to purchase the moving map S/W**
- **6 levels of reflectivity on NEXRAD products**

Echo Flight

1919 14th St., Suite 601
Boulder, CO 80302
(888) 739-7161
www.echoflight.com

POC: Rob Kalberer, President
(303) 818-7597

Product:

- **Echo Flight S/W and satellite transceiver communicator @ $1,795 (additional $180 for antenna)**
- **Flight Cheetah 270 MFD @ $5,995 turnkey package (inc. GPS and VHF antenna, S/W and transceiver)**

Availability:

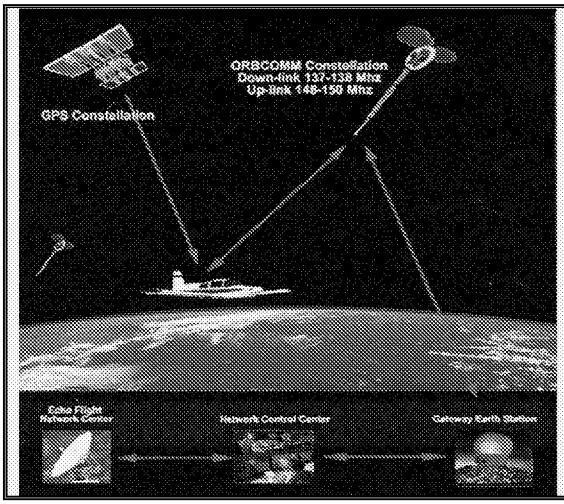
- **Current**

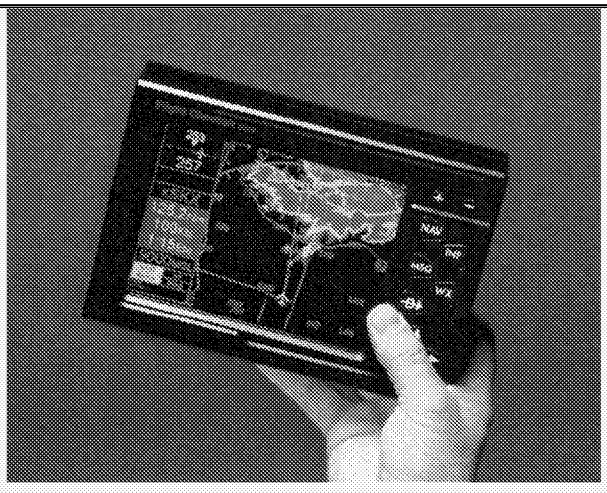
Weather Data Link:

- **Orbcomm LEO**
- **Weather provider is Meteorologix**

Features:

- **RS-232 serial port allows for use on laptop loaded with Echo Flight S/W; S/W can be used on Garmin 400 and 500 series MFD's**
- **MFD has modified display screen to reduce glare and improve brightness**
- **Subscription packages range from $9.95/month to $55/month plus $1 each access. Package deals available**
- **Composite NEXRAD, ceiling and visibility charts (graphical METARS), wind speed/direction, temp/dp spreads, METAR text (no TAFs)**
- **Compression and burst transmission mode technique (2.4Kbps uplink; 4.8Kbps downlink); 98% of requests within 20 minutes of receipt)**
- **R/R only, however, download intervals can be set up to emulate periodic "broadcast"**





Considerations:

- **No FAA certification for Flight Cheetah since it is portable**
- **Flight Cheetah 180 (smaller, cheaper MFD) not available yet**
- **Potential signal availability/response time issues (not statistically proven)**
- **4 levels of reflectivity on NEXRAD products**

Flytimer

Concord, MA
(978) 318 0600
www.flytimer.com

POC: Stan Durlacher, CEO
(978) 318 0600 x224
shd@flytimer.com

Product:	Features:
• **Transceiver-type with generic RS-232 connection; Interface to a MFD, Ipaq, or laptop** • **3 offerings planned: Low-end @$2,500, mid @$4,500, high-end @$6,500** **Availability:** • **Anticipated 4th quarter '02** **Weather Data Link:** • **ARINC/ACARS network** • **Weather provider TBD**	• **Developing an encoder to compress weather images over the slow network; 2.4Kbps up to plane** • **Recurring subscription costs TBD but "competitive"** • **STC certification for jets and twin-337; Anticipated for EFB** • **Anticipating TAMDAR probe to be integrated** • **Anticipated upgrade to VDL Mode2 with ACARS certification by late '02** • **"Auto-tunable" to fit into excess bandwidth**

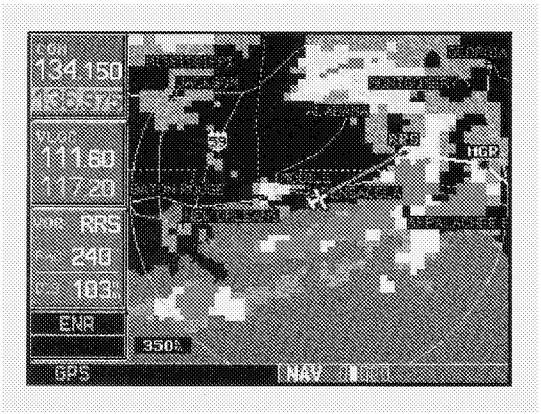
Considerations:

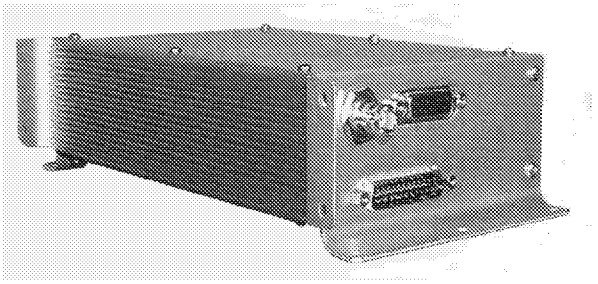
- **None determined**

Garmin
1200 E. 151st. Street
Olathe, KS 66062
(913) 397 8200
www.garmin.com

POC: Scott Smith, Manager of Sales
(913) 397 8200

Product:	Features:
• GDL 49 data link transceiver @ 3,495 **Availability:** • Current **Weather Data Link:** • LEO satellite • Weather provider is Meteorlogix	• Graphical weather provided R/R via strategic partnership with Echo Flight with same features • $9.95-55/month plus $1.00 each access; package deals available • Level D certification • 1 year limited warranty





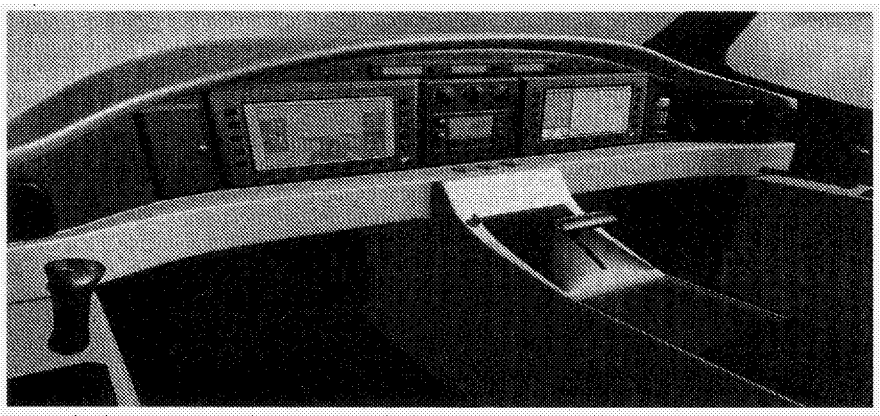
Considerations:

- Requires Garmin 400 or 500 series MFD's along with Echo Flight S/W and Orbcomm communicator
- 4 levels of reflectivity on NEXRAD products

Goodrich
5353 52nd. Street SE
Grand Rapids, MI 49512-9704
(616) 949 6600
www.goodrichavionics.com

POC: Ray Wabler, Business Development
(937) 426 1700 x3012

Product:	**Features:**
• **SmarkDeck integrated flight display** **Availability:** • **2003** **Weather Data Link:** • **TBD; Looking at GEO satellite**	• **Working on eliminating subscription costs** • **Nonrecurring cost of avionics TBD**



Goodrich's SmartDeck™ Integrated Flight Controls & Display System depicted in NASA's future cockpit concept. The SmartDeck primary flight display includes Synthetic Vision and Highway-In-the-Sky (HITS) format (left) and a Multi-Function Display with engine instrumentation (right).

Considerations:

- **None determined**

Honeywell Bendix/King

One Technology Center
23500 W. 105th Street, MD #45
Olathe, KS 66061-1950
(877) 712 2386
www.bendixking.com

POC: Gary Stuteville, Technical Program Manager
(913) 712 5545
gary.stuteville@honeywell.com

Product:

- **KDR 510 VDL Mode 2 Data Link receiver @ $5,495**

Availability:

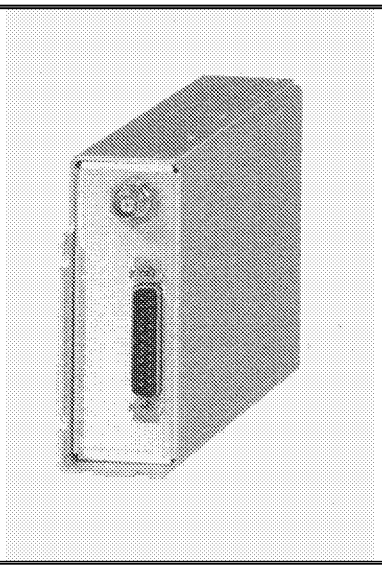
- **Current in areas where tower network completed**

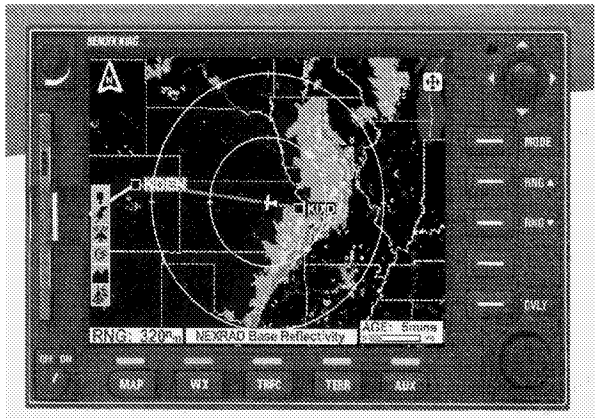
Weather Data Link:

- **VHF VDL Mode 2 ground-based broadcast**

Features:

- **Broadcast weather instantly available**
- **Display shows age of products**
- **Text weather free; Value-added graphics @49.95/month to $89.95/month based on yearly subscription**
- **Requires MFD; Receiver, interface, antenna, and display "system" priced @ $7,460 for non-radar-equipped aircraft, and $12,406 for radar-equipped aircraft**
- **Improved reliability in product availability due to storage and buffering**
- **2 year limited warranty**





Shown here displayed on a KMD 550 Multi-Function Display

Considerations:

- **Line of site constraints but available above 5,000 feet AGL as per FAA requirement**
- **Encryption for value-added products begins in 2003, otherwise currently free**
- **4 levels of reflectivity for NEXRAD products; 4km resolution**
- **Only 50 out of 200+ towers currently implemented (June 2002)**

Jeppesen
55 Inverness Drive East
Engelwood, CO 80112-5496
(303) 328 4779
www.jeppesen.com

POC: Matthew Ruwe,
Marketing Manager for Navigation S/W, GA Division
(303) 328 4779
matt.ruwe@jeppesen.com

Product:

- **FlightMap interface S/W @ $499**
- **AirCell Phone cost TBD**
- **Tablet computer display device@ $4-6K**

Availability:

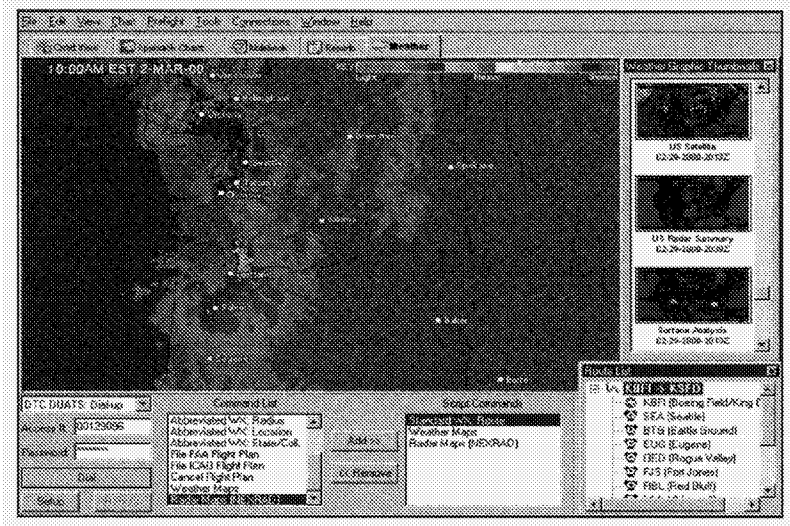
- **Current**

Weather Data Link:

- **Ground-Based Cellular Network via Aircell (Current)**
- **GEO Satellite via Satellite Technologies (Planned)**

Features:

- **FlightMap includes FlightStar Planning functionality**
- **Worldwide weather availability**
- **Unlimited downloads for about $20/month plus per minute call charges as applicable**
- **No certification issues as components are portable**
- **Priced for all aircraft and users**
- **30-day money back guarantee for FlightMap**



Considerations:

- **Update subscription plans to Navigational and FlightMap data are available from 1x a year to every 28 days**
- **"In-Flight" S/W under development to be released with Satellite link; Cockpit optimized interface**
- **Looking to develop interface S/W for display onto other commercial MFD's**
- **16 level reflectivity on NEXRAD products, 2km resolution**

Rockwell Collins
400 Collins Road NE
Cedar Rapids, IA 52498
(319) 295 1590
www.rockwellcollins.com

POC: Matt Smith, Manager of Advanced Products
(319) 295 7290
mtsmith@rockwellcollins.com

Product:	Features:
• VHF Radio 4000 @ $18K • Communication Management Unit @ $25K • Control Display Unit upgrade@ $10K or File Server Unit and Adaptive Flight Display (3010E) @ $40K **Availability:** • Current **Weather Data Link:** • ACARS ground-based commercial network; VDL Mode2 • Inmarsat satellite • Weather provider is Universal Weather	• Worldwide graphical weather products available over land or ocean; R/R • Weather products from $500 – 1500/month • High-end users; Compare functionality and costs with Universal Avionics, Honeywell (AFIS), and Teledyne systems • 25Khtz channels • 31.5 Kbps • Type certified for Challenger 601 by summer '03

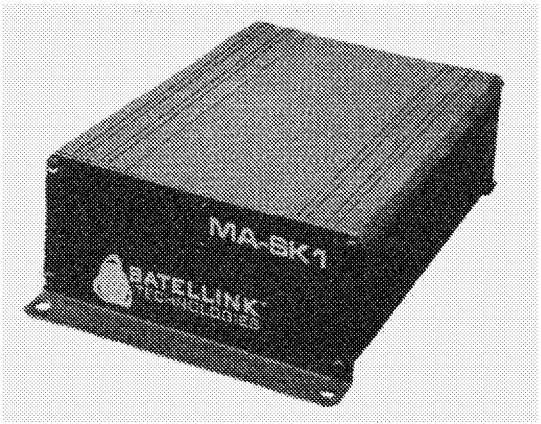
Considerations:

- **VHF has line of site issues**
- **Pricing given is for business/region/jet configuration – not the more rugged ARINC 600 connection (Air Transport)**
- **Plan to be compatible with FIS-B**
- **Cost to equip is geared to high end General Aviation users only**

Satellink Technologies, Inc.
21700 Atlantic Blvd.
Dulles, VA 20166
(703) 788 7010
www.satellinktech.com

POC: Harlan Hamlin, VP and GM of Aviation Services
(571) 238 5058
www.merlin.com

Product:	Features:
• **Merlin MA SK-1 receiver @ $3,500** **Availability:** • **Late summer 2002 planned launch** **Weather Data Link:** • **GEO Satellite** • **Weather provider to be Jeppesen**	• **MA SK-1 FAA certification planned after production** • **Continual broadcast of weather graphics to be displayed on various MFD's, EFB's, PC-based moving map displays, or portable units** • **Receiver cost includes 1 year of weather graphics; Otherwise$45/month unlimited access** • **TFR's and Flight Explorer ASD**



Considerations:

- **16 reflectivity level NEXRAD planned; 2km resolution**

Universal Avionics
3260 E. Universal Way
Tucson, AZ 85706
(520) 295 2300
www.universalavionics.com

POC: Paul Tews, PM for Multifunctional Displays
(520) 295 2300

Product:

- **Unilink CMU modem @ $20K**
- **Unilink CMU transceiver @ $28K**
- **Flight Management System @ $35K**

Availability:

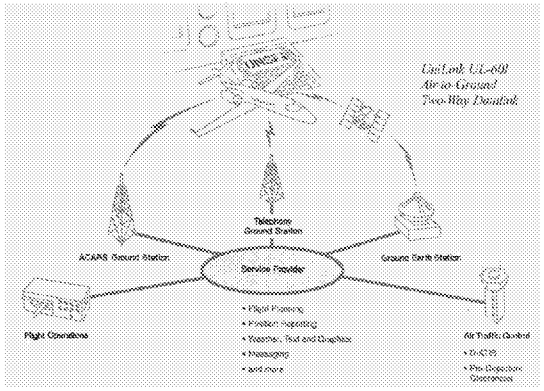
- **Current**

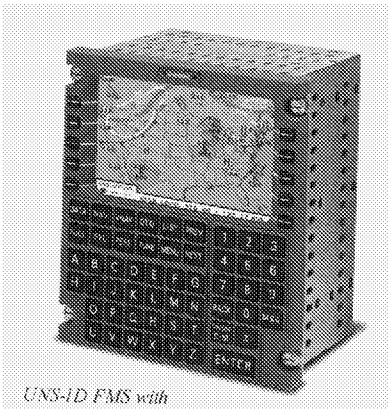
Weather Data Link:

- **ACARS ground-based commercial VHF network**
- **Inmarsat Satellite Communication**
- **Weather provider is Universal Weather**

Features:

- **Worldwide graphical weather products available over land or ocean; R/R**
- **High-end users; Compare functionality and costs with Rockwell Collins, Teledyne, and Honeywell systems**
- **Unilink can support up to 3 FMS units**





UNS-1D FMS with weather map displayed (SIG WX)

Considerations:

- **Cost to equip is geared to high end general Aviation users only**

UPS Aviation Technologies

2345 Turner Road SE
Salem, OR 97302
(800) 525 6726
www.upsat.com

POC: Jim Guitteau, Manager of Sales
(800) 525 6726

Product:

- **Apollo MX-20 MFD @ $7,295**
- **Interface S/W TBD**

Availability:

- **Planned late summer 2002**

Weather Data Link:

- **Ground-based Cellular Network via Aircell**
- **GEO Satellite via Satellite Technologies**
- **Weather providers are Meteorologix (for Aircell) and Jeppesen (for Merlin)**

Features:

- **Various functionality supported on the MFD**
- **Large 6" diagonal, high resolution screen; Direct sunlight readability**
- **Monthly graphical weather costs TBD**

Considerations:

- **Cost for Merlin service/equipage likely to be higher**
- **Working with Bendix/King to develop FIS-B interface**

Weather Services International

4 Federal Street
Billerica, MA 01821-3569
(978) 670 5000
www.wsicorp.com

POC: Keith Hoffler, Business Development Manager
Mobile Weather Division
(757) 865 1400 x221
khoffler@wsi.com

Product:

- **Pilot Weather Advisor Receiver $4,000-$5000**

Availability:

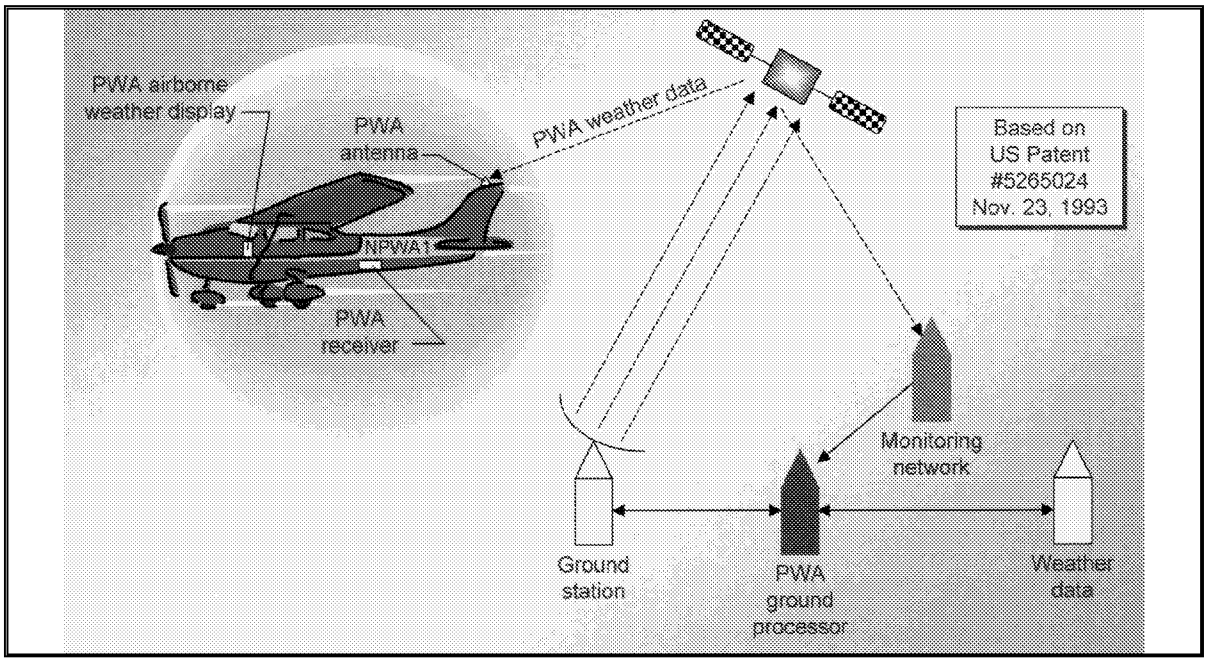
- **Late 2002**

Weather Data Link:

- **GEO Satellite**
- **Weather provider is WSI**

Features:

- **Continual broadcast of weather graphics to be displayed on various MFD's, EFB's, PC-based moving map displays, or portable units**
- **Less than $50/month for premium WSI graphics**
- **Meets RTCA DO-267 standards for usability and interoperability**
- **TFR's, NOTAM's, icing and turbulence graphics available**



Considerations:

- **Sandia Aerospace to build and certify receiver; Planned to be appropriate for all aircraft**
- **5 reflectivity levels on NEXRAD products, 2km resolution**
- **Uncertified receivers currently available**

Analysis of General Aviation Graphical Weather Data Links

Background

There are many commercial offerings that provide various types of graphical weather information to the cockpit. One key aspect that differentiates these system implementations is the communication data link employed.

The choice of the communication link is a major factor determining the accuracy, availability, timeliness, reliability, and integrity of airborne delivered weather products. The communication link also affects recurring cost to the GA operator as well as drives the nature of the service provided from broadcast to request-reply for strategic weather planning to tactical weather response.

Communication systems being utilized or considered to provide graphical weather data to the cockpit include both ground-based and satellite data links.

Commercial ground-based systems include: cellular networks as implemented by AirCell, the ARINC VHF ACARS existing infrastructure as proposed by Flytimer, and the VHF broadcast networks as developed by Honeywell Bendix/King and ARNAV. Although not commercially available, the ground-based Universal Access Transceiver (UAT) developed by MITRE and implemented in the Alaska FAA Capstone program can also provide broadcast weather data from the ground to the cockpit.

Low Earth Orbiting (LEO) satellites systems such as Orbcomm are utilized by GA weather system vendors including Echo Flight and Avidyne with a request/reply data link implementation.

Geosynchronous satellites (GEO) will provide continuously updated broadcast weather information to GA operators with proposed systems from Satellite Technologies (Merlin) and WSI (PWA).

Data Link Implementations

Ground-based VHF Communications/FAA FISDL Program

The FAA has agreements with two companies, ARNAV Systems, Inc. and Honeywell Bendix/King, to provide operational FIS Data Link (FISDL) services. The FAA has provided each company with two VHF frequencies located between 136 and 137 Mhz and provides management oversight including standards guidance. In return at no cost to the FAA, ARNAV and Honeywell are separately implementing their FISDL ground-based infrastructure to provide weather text and graphic products within the continental U.S. Aviation weather text products are provided free with weather graphics available from Honeywell and ARNAV with a monthly recurring cost.

ARNAV currently utilizes a VHF Gaussian Minimum Shift Keying (GMSK) digital data link and has FCC license approval for more than 50 future site locations. Honeywell adopted the VHF VDL-2 digital data link using which is the same RTCA standard that ARINC is transitioning to.

Honeywell is operational today in the Eastern half of the U.S. with approximately 50 VHF transmitter sites (as of mid June, 2002) with 120 planned by the end of this year. Since VHF transmissions are generally line of site dependent, GA operators using FISDL generally need to be operating at 5,000 feet AGL in order to receive FISDL broadcasts reliably. FISDL products conform to FAA and NWS standards outlined in the FAA Aeronautical Information Manual.

Since FISDL is a broadcast service, GA operators can receive continuous weather

systems updates in the cockpit as long as they are operating in areas where service is currently available and flying at or above 5,000 feet AGL.

Graphical weather system updates are frequent limited by NEXRAD updates every five minutes especially in the Western U.S. where there is much less overlapping coverage. Service may not be available to the GA operator when on the ground, flying at low altitudes especially in departure or arrival areas, and or in mountainous terrain where VHF transmissions may be blocked especially at lower altitudes. Ground-based VHF transmitters can also be impacted by adverse weather when GA operators flying in the same area may need critical weather information.

Ground-based VHF/ARINC ACARS Service

Many of the same concerns for line of sight coverage for VHF transmissions also apply to using ARINC ACARS service by General Aviation. ARINC VHF coverage is generally very good at altitudes of 5,000 feet AGL and above. Since ACARS is a two-way data link, companies offering weather service such as proposed by Flytimer can implement a request/reply service. Charges then can be set on a per usage basis. Frequent weather system updates in the event of rapidly changing weather could generate significant cost and that could limit GA service utilization.

ARINC is in the process of transitioning to VDL-2 service with a higher 31.5 Kb/sec data rate that would be more efficient and have greater capacity than the current ACARS of 2.4 Kb/sec.

Ground-based UAT Broadcast Service

The MITRE developed Universal Access Transceiver (UAT) for the FAA Safe Flight 21 and Capstone programs is a two-way broadcast data link system. Uplinked FIS broadcasts from ground-based stations include continuously updated weather (METARs, TAF and NEXRAD) information. TFRs and SUAs may be available in the future. Approximately 30% of the uplink bandwidth is allocated to weather data broadcasts. The UAT operates at 978 Mhz and has been produced by UPS AT for the Alaska Capstone program (175 equipped aircraft and ten ground stations). Avidyne will build UATs for the SE Alaska Capstone program. There is no GA cost estimate for Capstone UAT service.

UAT has been successfully demonstrated in both Alaska and in the Ohio valley with air cargo carriers (UPS, FedEX, Airborne). RTCA SC-186 has recently approved UAT Minimum Operational Performance Standards (MOPS). National Telecommunications & Information Administration Stage 3 spectrum allocation approval is complete and the FAA has initiated a final Stage 4 action request. FAA has announced a link decision that is the UAT for low flying aircraft including most GA and 1090 Mhz primary for high flying aircraft which already are so equipped.

Preliminary results of limited aviation safety fatality data related to weather in Alaska indicate that the Capstone program and UAT equipped aircraft have seen a reduced accident rate to date. A large number of ground stations, however, would be required in the continental U.S. to provide these services especially to altitudes below 3,000 feet AGL and in terminal areas. That could require between 300 and 500 ground stations to achieve that coverage. FAA communication sites could be candidates for UAT sites. This approach would integrate several aviation services as desired by GA operators and AOPA.

Cellular Communications

AirCell provides voice and data communications to General Aviation through a nationwide cellular network. AirCell has installed transceivers and upward looking antennas on U.S. ground-

based cell phone towers. Service availability as with any cellular network may be dependent on specific geographical location as well as altitude. AirCell can provide antennas for aircraft installation to provide cellular phone service both on the ramp as well as airborne. A data/fax modem is required to receive weather data.

AirCell uses a request/reply system with airtime charges of about $2.00 per minute. Service plans available begin at $9.95 per month for data only services.

Nonrecurring equipment costs and aircraft installation are comparable to other service providers for operators who do not have AirCell service installed in their aircraft. GA operators may choose to limit their weather data updates knowing that there is a cost with each update. Frequent updates on a continuous basis should contribute more to aviation safety assuming the GA operator takes advantage of the weather information available. AirCell, however, can also provide cellular phone service.

Low Earth Orbiting (LEO) Satellites

Several weather data link service providers including Echo Flight and Avidyne are marketing systems that use LEO satellites such as Orbcomm. They use a request/reply implementation. Orbcomm has separate VHF uplink and downlink frequencies. Service charges are applied on an access basis. Weather data is received in approximately 2.5 minutes after a request is sent. Automatic weather updates can be programmed for regular intervals of every 15, 20 or 30 minutes as desired. Service packages are available with monthly charges priced according to usage rate.

Request/reply systems require aircraft onboard transceivers. VHF antennas required for aircraft installation for Orbcomm satellite data link are larger compared to L or X band antennas used by other service providers. Satellite coverage generally is good and reception is available down to the ground. GA operators may obtain weather service products over both land and water compared to physical limitations placed on ground-based transmitters.

The cost of having this capability in the GA cockpit, however, is directly related to frequency of usage. While that might be fine for the GA operator with limited needs, it may also be a disincentive to the higher usage operator who may restrict weather information requests with associated safety tradeoffs because of cost avoidance. Weather data must be current to be of value to GA.

Geosynchronous (GEO) Satellites

New offerings to be available this year to GA operators include continuous GEO satellite weather broadcast services. The Merlin system from Satellink Technologies and the Pilot Weather Advisor formerly a division of Vigyan Inc. and now part of WSI Inc. are currently marketing graphical weather services. A small low drag antenna installation is required along with a satellite receiver. Along with graphical weather displays, a variety of other data is anticipated over time including METARs, TAFs, NOTAMs, and PIREPs. Merlin advertises availability of TFR graphics and ATC delays with Flight Explorer's FE InFlight service.

Since these services use satellite broadcasts, they are geographically available everywhere including on the ground or in the air. Weather data is updated frequently at approximately five minute intervals for a flat rate monthly fee. Availability and system reliability should be high since this is a receive only system and there is no large ground-based infrastructure to support. Current service providers do not have a significant user base at this time. This system approach, however, appears cost effective and is very promising for GA weather data link acceptance.

Comparison and Analysis of Airspace Coverage for Graphical Weather Providers

Ground and airspace coverage of graphical weather products for GA are constrained by the choice of the communication data link selected by the service provider and the network implementation status. A summary of geographical coverage for service providers is as follows:

Ground-based Cellular

AirCell is the communication service provider and offers aircraft antenna options for both airborne and ground communications. An Aircell data/fax modem is required to receive their graphical weather products. UPS Aviation Technologies, Control Vision and Jeppesen also offer weather to the cockpit via AirCell cellular communications. AirCell advertises nationwide coverage. As with any cellular system, some coverage gaps will exist depending on tower locations and terrain. With advertised connectivity to both ground-based and airborne cellular networks, aircraft altitude should not be as limiting a factor as it is with ground-based VHF systems.

Ground-based VHF and UAT

Ground-based VHF broadcast service providers include Honeywell Bendix/King and ARNAV under the FAA FISDL agreements. As previously discussed, there may not be availability of weather information except when airborne and generally at an altitude of 5,000' feet AGL or above.

Honeywell currently has airspace coverage over most of the Eastern U.S with expansion plans in 2002 and subsequent. ARNAV is currently expanding coverage in the U.S.

Rockwell Collins and Flytimer have request/reply systems which are currently using the ARINC VHF ACARS service which has good nationwide coverage with similar minimum altitude requirements.

UAT service, if implemented, has similar line of sight limitations and is higher in frequency than VHF. The coverage that could be made available is directly related to the number of ground stations. It is anticipated that ground station UAT coverage would be comparable to VHF. Between 300 and 500 ground stations might be required to achieve coverage down to 1,000' feet AGL in the U.S.

Satellite Based

Graphical weather service providers utilizing communication links over either LEOs or GEOs generally have airspace coverage over the entire U.S. down to ground level.

Service providers using LEO satellites utilize a request/reply system. These include Echo Flight, Garmin, Avidyne, ARNAV and Control Vision. Echo Flight, Garmin and Avidyne use the Orbcomm satellites while ARNAV and Control Vision have agreements with the Global Star satellite network.

Merlin and PWA satellite broadcast services use GEO satellites. The Merlin service is also utilized by UPS Aviation Technologies.

Independent of the satellite weather service provider, system coverage will generally be better than with a ground-based network service provider. These performance parameters indicate hybrid systems using satellite broadcast for nationwide data and ground stations for local near real time weather data may provide the best overall weather system approach to meet general aviation weather needs.

Analysis of Recurring and Nonrecurring cost for Graphical Weather Providers

There is both a nonrecurring cost and a recurring cost to GA operators who want

graphical weather data in the cockpit. Some service providers will provide text products free of recurring charges such as Honeywell and ARNAV under the FISDL program. Recurring charges apply for graphical weather displays.

Nonrecurring costs

Graphical weather service provider system costs not including displays typically vary between $2,000.00 and $5,000.00 as detailed in the vendor matrix summary. This generally includes an FAA certified data link transceiver or receiver only, aircraft antenna and related interface controls. Aircraft installation can vary between 10 to 20 percent of the system equipment cost.

Portable electronic displays or certified installed aircraft avionics displays will generally cost between $5,000.00 and $15,000.00 depending on aircraft configuration, display size and functionality. Specific displays and associated costs are included in the vendor matrix in the Appendix. Low cost display options include laptop computers that may be awkward in the cockpit and PDAs, such as the Compaq IPAQ, that have small display size and may not be compatible with some service providers.

Recurring Costs

GA graphical weather service providers are generally competitive on subscription costs. Recurring costs can be differentiated between request/reply systems and continuous broadcast services. Specific monthly and/or annual plan costs are included in the vendor matrix summary. Service providers utilizing request/reply systems generally have a range of plans that vary as a function of the number of minutes or requests allocated per month. Plans start at $9.95/month and a $1.00 for each request. Broadcast services that provide continual updates have service plans that typically run from $40.00 to $50.00 per month.

Nonrecurring Cost Analysis

According to the NASA Langley and Embry-Riddle survey, "General Aviation Pilots' Perceived Usage and Valuation of Aviation Weather Information Sources", February 2002 [9], over 88% of the GA respondents were willing to pay under $5,000 for the in-flight weather system.

A study previously performed by Kauffmann and Pothanun from Old Dominion University, "Estimating the Rate of Technology Adaptation for Cockpit Weather Systems", 2000 [10], revealed that the average acceptable cost for in-flight information systems on a moving map was just under $6,000.

In the Kauffmann study, the cost categories were more sensitive and were noted as a possible cause of the higher acceptance cost results. If a combined survey result of approximately $5,000 was used as a cut-off point for nonrecurring charges for in-flight weather information, then several of the surveyed commercial vendors have their current price-points too high for perceived successful market penetration.

For example, only the offerings from Aircell, ControlVision, and Jeppesen currently fall below this cost threshold assuming that the pilot does not have a MFD already in the cockpit. If such a display device already exists, and the pilot selects a vendor whose receiver and software are compatible, then several other offerings are under the cost threshold. The cost of the display device is, in most cases, the cost driver.

Survey results derived from the referenced NASA study showed that over 75% of respondents were unwilling to pay over $1,000/year for a weather graphics subscription service. The Old Dominion study deduced an average of just under $500/year or about $40/month. However, the respondents included avionics and

airframe manufacturers, and trade groups rather than individual end users.

In a subsequent study by Kauffmann, Sireli, and Ozan, 2001, "A Market Research Study for Future Weather Information Systems in General Aviation" [11], 70% of private and instrument-rated pilots expected recurring costs to be less than $2,000/year while 81% of recreational pilots expected recurring costs to be less than $500/year.

According to the results of these surveys, the recurring costs for commercial weather product offerings reviewed in this study are within cost thresholds.

The exception to this are those vendors currently providing weather graphics and avionics to the highest GA users. These vendors include the Teledyne Telelink, Universal Avionics Unilink, Honeywell AFIS, and Rockwell Collins IDC systems. However, these vendors are all competitive among themselves in the high-end markets they serve.

Analysis of Request-Reply Versus Broadcast

For some GA operators who want graphical weather and who may share an aircraft and/or fly infrequently, a request/reply system may be more cost effective. This statement is consistent with previous survey results where the desire to 'pay by access' was documented in the 2002 NASA and Embry-Riddle study. This study showed that over 40% of GA pilots surveyed preferred this method over a 'pay by month' (27%) or 'pay by flight' (17%).

The knowledge, however, that each update will either have an incremental cost or use up an allocated number of requests could inhibit some operators from obtaining weather updates or at least limiting their frequency. The time delay to receive an update could be significant especially if previously obtained weather data had aged considerably. This generally is not an issue with broadcast services where data is usually updated about every five minutes. It should be noted, however, that since request/reply systems have a two-way data link, non weather related air ground data communications can be requested and/or transmitted by the GA operator.

In reviewing in-flight aviation weather for general aviation it must be noted that there is an extensive two-way radio communication infrastructure in place to serve ground and airborne flight planning and weather information requirements. This infrastructure is the FAA's Automated Flight Service Station (AFSS). Airborne communications are supported from the AFSS En route Flight Advisory (EFAS) position. While AFSS services have been invaluable to GA, there are nevertheless notable challenges that provide opportunities for the development of cockpit weather graphical display systems.

In summary, there is not a clear cut cost tradeoff between request/reply and broadcast. Some aircraft may already be configured with avionics that can be modified with minimal nonrecurring cost to obtain graphical weather data. Some GA operators who are not willing to pay for expensive MFDs may prefer to use their own portable display including Laptops or PDAs. The tradeoff between a broadcast service and a request/reply service may be related to how frequent the GA operator may fly, where he may fly and whether he flies VFR and/or IFR.

Analysis of Avionics Displays including Size, Mounting Considerations, Portability, and Power

In addition to cost, there are other considerations that can increase the useability of having graphical weather in the cockpit. These include the size of the device where the graphics are displayed, where in the cockpit is the display mounted, how is the display mounted, and electrical or power issues that are required. Some of

these considerations fall into human factors issues and will not be discussed at length here. A comparable analysis of current offerings, however, are addressed.

Panel Mounted Display

The majority of commercial vendors surveyed offered either their own panel-mounted type display device, usually designed to be mounted in the center of the instrument panel, or the ability to display on a similar device manufactured by another vendor. Most were MFD's. Only Aircell, ControlVision, and Jeppesen current offerings were not compatible on panel-mounted MFD's.

The preponderance of panel-mounted displays appears to be consistent with the Kauffmann, 2000 survey findings which found that approximately 2/3 of GA users surveyed preferred the weather display to either be integrated into current cockpit display systems or as a separate stand-alone panel mounted cockpit display.

These results were additionally consistent with Burt, et.al., 2000, "Impact of a Weather Information System Display on General Aviation Pilot Workload and Performance"[12], which concluded that pilots preferred the display mounted in the center of the instrument panel followed by the display mounted in the center of the control yoke.

Panel-mounted display devices were fairly comparable in size, shape, and power usage. Of the displays reviewed, most had a diagonal viewing area of approximately 4-6" with the largest being ARNAV's ICDS 2000 and Avidyne's EX5000 at a diagonal of over 10".

Input power used for these displays generally falls in the range of 10-33 VDC. UPS Aviation Technology Apollo MX-20 draws 40 watts maximum and the ARNAV ICDS maximum input power is 50 watts.

Non-Panel Mounted Display

Echo Flight's "Flight Cheetah" is the only portable MFD reviewed. It has a 6.4" diagonal screen and requires between 10-35 VDC. It is important to note, however, that the Garmin panel mounted 400 or 500 series will also display Echo Flight graphical weather products.

The Aircell and ControlVision offerings display weather graphics on IPAQ devices that use minimal power. However, screen size is considerably smaller than any of the MFD's reviewed.

Jeppesen weather graphics are currently viewed on any Windows compatible laptop computer of which there are several manufacturers.

Receiver/Transceiver

There are several commercial offerings that require the purchase and mounting of receiver or transceiver hardware. The mounting can be temporary or permanent. In all cases the mounting can be horizontal or vertical.

Size of the equipage is also similar with most being approximately 7-9" long, 5-7" wide, and 1.5-3" high. Power requirements are similar – generally in the range of as little as 6 to a maximum of 32 VDC.

Analysis of Display Functionality in addition to Weather Graphics

There are several other technologies which bring information to the cockpit that are as or more important to the GA pilot for decision making. These include traffic, terrain, and moving maps that contain navigational information.

It has been suggested by informal surveys performed by AOPA that these kinds of information become more valuable for pilot decision making when combined with graphical weather over graphical weather

alone. This has been more statistically proven by Kauffmann, 2000, which showed that over 60% of GA survey participants believe that the combination of moving map and GPS with graphical weather is a product success factor for the GA market segment.

Multi-Functional Displays

In almost all cases, the vendors surveyed had a current product offering or planned offering that allowed graphical weather products to be displayed with other valuable technologies.

For example, the Honeywell Bendix/King KDR 510 receiver allows for graphical weather to be displayed on the KMD 550 or 850 MFD's along with traffic, terrain, position, moving map, and flight plan. The flight plan and traffic can be overlaid with graphical weather.

Additionally, if the aircraft is equipped with on-board radar, electrical discharge information can be overlaid with NEXRAD images. Terrain graphics cannot be overlaid with weather due to similarity of colors used for graphical weather.

ARNAV's MFD 5200 can display graphical weather along with terrain information. Their Terrain Obstruction Proximity System (TOPS) icons indicate where terrain is in the path of the aircraft over the next 60 miles at the current aircraft altitude. The icons are the same color as strong reflectivity echoes so it is unclear what is depicted if strong reflectivity returns are directly over the terrain icons.

Echo Flight's Flight Cheetah allows for overlay of graphical weather with other technology such as approach overlays and terrain alerts. It should be noted that the enhanced mapping functionality, which depicts terrain contours, is a better overlay than the terrain alert functionality with graphical weather due to different colors used. As with the Honeywell system, the terrain alert map uses similar colors to the reflectivity levels on NEXRAD products. The Flight Cheetah does not have traffic functionality at the current time.

Garmin 400 and 500 series MFD's allow for overlay of graphical weather information. These include a dedicated weather only display, a separate moving map with weather and flight plan display, a traffic and weather display, and if the aircraft is equipped with a Goodrich Stormscope on-board radar, electrical discharge information can be overlaid as well.

ControlVision's Anywhere WX offering allows for the overlay of graphical weather information onto a moving map display, flight plan, traffic, and terrain. However, the display used is the IPAQ and as such, the display size is considerably smaller than the average panel-mounted or Echo Flight portable MFD.

The Aircell offering only depicts graphical weather information by itself. There is no moving map so there is no proximity of weather to the current aircraft position information. Further, Aircell does not currently offer any other functionality to overlay with graphical weather.

Analysis of Graphical Weather Products

The objective section described several pilot decisions that can be affected by weather. Graphical weather product requirements should be defined in terms of these decisions so that product content, timeliness, and display characteristics can be of value to the GA pilot.

Analysis of GA Weather Needs

Part 91 weather related accident causes or factors statistics for 1989-1997 illustrate that winds have by far produced the most incidents at 43%. Incidents caused by visibility and ceilings produced 24%, turbulence 8.5%, precipitation and density altitude 6%, thunderstorm 2% and windshear 1%.

The study by Keel, et al., 2000 [13], showed that the need for specific weather information varies by phase of flight from en route to approach to landing. Thus, while all of these weather phenomena are important to the GA pilot, their relevance, or focus towards making operational decisions shifts by phase of flight. These include spatial or temporal factors, strategic or tactical use, and display characteristics.

For example, for en route operations, it is important for the pilot to have access to ceiling and visibility information along the flight path to determine if the flight will continue under VFR or IMC conditions. In the approach and landing phase of flight, short-term forecasts at destination airport(s) become important to determine an alternate airport if the destination airport is below minimums. In both cases, a cloud top and bottom graphic would assist in these types of decisions but the focus in both temporal and spatial factors would be vastly different.

In another example, wind information at flight level is critical for both IFR and VFR operations to determine fuel burn and potential to hold or reach the alternative airport. Approach and landing decisions would be more affected by low-level wind shear and crosswind component on the runway.

If flying IFR, icing information is very important en route to either stay above, below, or avoid altogether so that icing encounters are avoided. For landing decisions, surface icing information becomes important to determine breaking distances.

Convective activity along the intended flight path is important for re-routing. However, trend information for reflectivity mosaics, while of some relevance for ground-based strategic planning, tend to be less useful for more tactical pilot decision making (i.e., short-term (30 minutes) forecasted movement of reflectivity cells). This is because neither the future movement of convective cells nor storm growth and decay are linear in time and space. The pilot would find a short-term extrapolation of where cells are expected to be, along with cell strength, much more valuable towards a modification of flight route. In this case, advanced scientific algorithms will have taken much of the guesswork away from the pilot.

Operational decisions can also be affected by level of reflectivity. It can be argued that the 30DbZ reflectivity threshold can be used as a good indicator of the airspace changing from VFR to IFR conditions and the 40DbZ reflectivity threshold can be used as an indication of the onset of convection. If an additional reflectivity level for extreme convection is also shown, it can be concluded that for the GA pilot, the relative value of more than 3 or 4 reflectivity levels decreases quickly for aviation decision making.

PIREPs can also be quite useful for decision making but it must be understood that the same weather can and does affect different aircraft in different ways. Pilot experience will also influence a particular weather's effect on operations. Lastly, the information contained in a PIREP can be ephemeral in both space and time, meaning highly perishable. A PIREP graphic that is an hour old will have limited value.

In the approach phase, the GA pilot will require similar kinds of information as in the en route phase but the display of the product must have a much higher glance value due to limited pilot attention. Products that have no interpretive aspects and are free of multiple colors, lines, or depictions become much more valuable.

In the landing phase, GA pilots will require a final update on runway winds, visibility (although as previously indicated, VFR pilots will make landing decisions based on 'personal minimums' and are not regulated by airport minimums), and surface icing for

braking considerations. During this phase of flight the availability of graphical weather products may have limited use due to other pilot duties required and the overall lack of time and attention available.

Other considerations that should not be overlooked are weather conditions such as temperature, humidity, wind speed and wind direction that directly effect aircraft performance. These are important pre-fight as well as in-flight considerations and can affect a variety or operational decisions such as determining aircraft service ceilings and acceptable takeoff and landing lengths.

In addition to aircraft performance factors weather considerations are also an issue of pilot convenience and comfort, especially for small general aviation aircraft without air conditioning, or without adequate cockpit heating. Turbulence remains a concern. For example, flying above summertime scattered clouds can be an enjoyable flying experience as opposed to below those same clouds in turbulent conditions.

Weather Graphics Available to GA Pilots via Data Link

Most of the graphical weather products currently offered to the GA pilot via data link are quite similar. They appear to have been driven by current data link technology and perceived GA pilot weather needs by commercial vendors. This is in contrast to graphical weather needs being driven by the operational decision-maker.

Graphical products include composite NEXRAD mosaics and graphical METARs. Some other commercial offerings provide other aviation graphics such as ceiling and visibility, icing, and turbulence charts from the Aviation Weather Center. These additional charts are already available to ground-based decision-makers for strategic planning. Further, making these products available to a greater potential market, such as GA pilots in the cockpit, serves these companies well as additional sources of income at little additional cost. However, the value of these products towards GA pilot decisions is quite limited at the expense of available limited bandwidth.

With regard to available graphics, Aircell and ControlVison currently only offer NEXRAD mosaics. The Aircell graphic is static, meaning that there is no moving map and the GA pilot does not necessarily know where the plane is with respect to the precipitation. The mosaic offers 16 levels of reflectivity at 2km resolution. However, as indicated earlier, 16 levels of reflectivity probably has limited additional value over 3 or 4 levels.

The NEXRAD composite shown with ControlVision's Anywhere Map is depicted in 6 levels with 2km resolution. The difference here is that the reflectivity is shown on a moving map display and the pilot can see where the aircraft is with regard to potentially significant weather.

Echo Flight currently offers NEXRAD composites, ceiling and visibility, precipitation, wind speed and direction, temperature and dew point spreads, and graphical METARs. The NEXRAD product is shown in 4 levels (3 colors) and from 8km resolution for a national depiction to 2km resolution for regional depictions.

Garmin depicts similar weather products on their MFD's as they receive weather information from Echo Flight. Garmin also provides electrical discharge information overlaid with NEXRAD graphics if the aircraft has a Goodrich Stormscope on-board radar.

The indication of electrical discharges enhances pilot awareness of convective activity and relative storm strength above and beyond simple depiction of 40 DbZ reflectivity contours. This can assist IFR pilots in making the widest avoidance possible from the convective activity. Additional value to the lower-end GA or VFR only pilot is much more limited as

these users would not likely be able to afford the relative expensive Stormscope equipage and the fact that they would not likely be flying in any vicinity of convective activity.

ARNAV premium graphical weather products, as available over their ARNAV proprietary network, include NEXRAD composite graphics, winds aloft graphics, significant weather report graphics including 3-D turbulence and icing graphics, graphical METARs, and National Convective Weather Forecast (NCWF) 1-hour products. The NEXRAD graphics are shown with 4 levels of reflectivity and a 64km resolution for national mosaic and 8km regional mosaic. The regional mosaic comprises the area within 150nm from the aircraft. NOTE: FISDL graphical weather products are to include the national and regional mosaics at the same resolutions mentioned, and graphical METARS. However, these are not currently available via FAA provided frequencies.

Honeywell Bendix/King graphical weather products include NEXRAD composite mosaics, graphical METARs, and lightning graphics. Both national and regional NEXRAD mosaics are depicted in 4 levels of reflectivity and 4km resolution. NEXRAD composite mosaic reflectivity animation is planned.

Jeppesen weather products include NEXRAD composite graphics with 16 levels of reflectivity and 2km resolution. Additional graphics are numerous and include winds aloft, significant weather prognostications, surface weather analysis, wind and temperature forecasts, etc. As indicated in the opening paragraphs of this section, these kinds of charts had limited value to GA pilots while en route. This is consistent with the results of the NASA and Embry-Riddle study.

Graphical weather products planned from other vendors not currently offering data link services are not evaluated in this section. However, a sampling of planned products are listed in the detailed matrix in the Appendix.

Conclusions

Weather Data Link Conclusions

Analysis of current and projected communication data links for providing graphical weather data to the cockpit indicates that a broadband satellite broadcast implementation is effective for timely, strategic GA flight planning. Ground-based broadcast service of local and/or airport terminal weather conditions could complement and/or enhance satellite broadcast service by providing more tactical GA flight planning information.

Aviation weather providers are now offering continuous broadcast services over GEO satellites channels with adequate bandwidth. Satellite digital radio service providers could also be candidates for satellite broadcast of aviation weather data. GEO satellite transmission time delays are not a factor for this type of GA advisory information.

Ground-based candidates for broadcast of local weather conditions include the recently FAA selected L band UAT data link and the VHF VDL-2/3 data links. Weather data transmission loads per RTCA documents [14] indicate that UAT and VHF data links will support local graphical weather services to the cockpit.

In order to facilitate accelerated GA acceptance of weather data links, weather information services must be provided in conjunction with other aviation communication services. These services could include ADS-B, TIS-B, voice communications, GPS moving map displays, and satellite-based navigation aids for en route and terminal navigation. These services need to be incorporated into multifunctional avionics to reduce weight, power and space requirements while limiting cost and taking into account human factors issues for GA pilots.

In addition to limiting nonrecurring avionics cost, recurring cost must be affordable to the low end GA community to achieve significant utilization. This could be accomplished if data link transmission costs are significantly reduced or eliminated for aviation users. Recurring subscription costs might then be based solely on charges for weather and aviation related flight products. This would require the Government to provide free aviation data communication data link transmissions in a similar manner to current FAA voice communication services .

Graphical Weather Product Conclusions

Weather needs for aviation have, in general, been derived in three ways. They have been derived by meteorologists or other non-aviation users, as opposed to NAS decision-makers, they have been derived by phase of flight, and they have been derived by technology that is currently available.

Unfortunately, each of these methods is flawed and has lead to the development of products that do not entirely satisfy the end user's weather needs. It is becoming more understood that aviation weather needs are derived by operational decision making and the kinds of weather, product content and focus, and display characteristics that affect those decisions.

Weather needs derived by non-users will invariably not be satisfactory because of their lack of operational understanding that is required to develop valuable aviation focused weather products. Many aviation products contain far too much information than is necessary for aviation operational decsion-making. NEXRAD mosaics that contain 16 levels of reflectivity are a good example of this.

Weather needs derived by phase of flight is only partially satisfactory. While an understanding of the kinds of weather that affect operations during specific phases of flight will be revealed, and is important, a breakdown of this methodology occurs when it is realized that the same operational decisions can be made in different phases of flight. For example, while en route, encountered windshear activity that has not been forecasted can cause a change in route or altitude. However, windshear encountered in the approach or landing phase of flight may cause an escape decision. In other words, the GA pilot will have different "options" depending on the phase of flight when aviation-impacting weather is encountered. This leads to the need for similar products but with differing focus. As mentioned in the analysis section, focus can change for strategic or tactical use, spatial and temporal extent, or display characteristics.

If technology is allowed to drive weather needs, satisfaction of that need may never be achieved. For this reason it is important to separate weather *needs* from weather *requirements*. Weather needs should be derived based on operational decisions, not technology (solutions). As long as operational missions do not change, properly defined weather needs will not change. Once understood what weather and appropriate characteristics (focus) affect operational decisions, technological solutions can then be evaluated towards satisfying those needs. These solutions become the weather requirements. Weather requirements can change with time as technologies improve. Concepts of Operations are classic examples of how perceived improvements in technology will better satisfy user needs at specific future points in time.

For this particular study, the assessment of data link technologies for bringing graphical weather to the GA cockpit appears to be technology driven, not user driven. In order to properly assess data link solutions, GA graphical weather needs must be defined first. Because such needs have not been validated, commercial providers have no way of knowing what products or product characteristics to provide to the cockpit.

Currently, GA graphical weather needs do not appear to have been well defined or validated. Where there have been attempts to do so, the methodology may have been flawed. By focusing on GA user operational decisions, specific graphical weather needs can be identified.

For example, specific graphical weather needs may include a particular set of products required for decision making. Some of these products may be required during all phases of flight while some others may not. Some may require much bandwidth. Others may require less bandwidth but need to be extremely timely, perhaps every 30 seconds. While en route, operational decision making may be satisfied by requesting graphical weather product updates only when deemed necessary. When making approach or landing decisions, perhaps the pilot will not have time to request graphical weather products. In this case, a continuous broadcast may be necessary and, suffice to say, availability below 5,000 feet AGL is obvious.

While not a driver for specific data link technologies, an important factor to maximize the value of graphical weather to the GA user is specific product characteristics and how they may change based on decisions made during each phase of flight. This includes product resolution, accuracy, display, and integrity. GA operational thresholds also need to be considered in order to determine certain product characteristics. A good example of this was mentioned earlier regarding the number of reflectivity levels depicted in a composite mosaic.

Where resolution and accuracy will certainly change as the pilot moves from the en route phase to approach. For example, a resolution

of 2 or 4km for convective cells may be quite satisfactory while en route. This can be driven by the expectation that reasonably precise navigation allows for a 2–3 mile lateral deviation from filed flight path. However, lateral deviations decrease significantly in the approach phase of flight. Resolutions of 1km or less for convective cells may be necessary for operational decision making.

Integrity can be defined as the minimum percent of validation (for whatever product characteristics apply) that the decision maker will accept before using the product "with confidence". To this end, a forecast product that projects convective activity 2 hours in the future, with a certain resolution and accuracy, may have an integrity of 70%. This means the convective activity within this resolution and accuracy will be valid 70% of the time. However, a 30 minute forecast may require an integrity of 80 or even 90% before it is used for decision making.

In conclusion, once a well defined standardized set of GA graphical weather products is validated based on decisions affected, when they are needed, and their characteristics, then various data link solutions can be properly assessed to determine which architecture can best satisfy the users' graphical weather needs.

Recommendations for Future NASA Research and Development (R&D) Efforts

Recommendation I

- **Flight test and evaluate representative commercial weather data link systems.**

A flight test and evaluation of some or all of the surveyed vendors in this report is recommended. NASA should obtain at least one system of each representative technology and conduct an objective evaluation utilizing a typical GA aircraft types flown by a diverse group of GA pilots.

NASA could contract out this evaluation, if desired, to an independent aviation company or an aviation oriented university. The FAA, for example, has contract vehicles with universities including a multi-university Center of Excellence for General Aviation with over three hundred training aircraft. The lead university in this consortium is Embry-Riddle University.

This flight testing should be conducted in representative GA aircraft with as a diverse group of pilots as practical to perform evaluations. Pilot members of professional organizations such as AOPA, EAA, NBAA, etc. could participate. The results of this evaluation would indicate which current technologies have the greatest potential for accelerated market penetration.

Follow-on R&D efforts could then be explored to further reduce nonrecurring and recurring costs of the preferred technologies for GA operators to increase market penetration. As indicated by an Embry-Riddle pilot survey, these costs significantly influence GA pilot interest and utilization of weather data links.

Recommendation II

- **Investigate FAA NEXCOM VDL-3 data link FIS services**

It is recommended that NASA initiate an R&D effort to investigate FIS utilization of the new VHF VDL-3 two-way digital data link standard proposed by FAA for their Next Generation Air/Ground Communication (NEXCOM) program. It should be tested and evaluated for aviation weather data link applications. Assuming prioritization is incorporated for all ATC message traffic over VDL-3 data channels, FISDL information including text and graphical weather should be evaluated for ATC VDL-3 transmissions on a not-to-interfere basis.

While VHF VDL-2 GMSK and CSMA data links are currently being used today, the VDL-3 Time Division Multiple Access (TDMA) implementation being proposed by FAA for ATC voice and data communications in the NAS will be initially operational about 2009 with GA utilization towards 2020. Ground-based VHF VDL-2 and UAT broadcasts should be compared with VHF VDL-3 TDMA weather data transmissions for accuracy, efficiency and timeliness.

Assuming VDL-3 potential for GA graphical weather, NASA should coordinate with the FAA NEXCOM team to investigate future integration of weather data link services in the NAS for GA and commercial aviation.

Since FAA has always provided VHF ATC communication services at no cost to NAS users, presumably there would not be communication service charges for weather

data linked to the cockpit by FAA. This could significantly reduce the cost of weather services to GA by eliminating the communication charges currently passed on by aviation graphical weather service providers.

GA users would only require a new multimode VDL-3 digital capable along with an appropriate avionics display. This could address the desire by many GA operators and organizations to have a single radio provide multiple functions and services to the cockpit.

Recommendation III

- **Develop R&D partnership with XM and/or Sirius Satellite Radio to investigate their use for FIS**

NASA has investigated the use of state-of-the-art satellite digital audio radio systems (SDARS) for delivery of weather information as highlighted in NASA research paper by Stough and Martzaklis [15]. This paper indicated the feasibility of SDARS for FIS transmission to GA aircraft was demonstrated successfully in South Africa in 1999 using the AfriStar SDARS satellite.

Sirius and XM Radio are the current satellite service providers in the U.S. XM Radio and Sirius advertise approximately 100 entertainment channels with a subscription price of $9.99/month for XM and $12.95/month for Sirius. If these satellite radio broadcast service providers could see a business case for also carrying graphical and text weather products, this would be very attractive to aviation as well as some marine and ground transportation U.S. operators.

GA pilots could display not only weather information in the cockpit, but could listen to digital CD quality musical entertainment as well as news, sports, business, etc. Graphical weather data would most likely increase the subscription cost although the delta increase would be dependent on the number of users ultimately signed up by SDARS providers.

It is recommended that NASA establish and R&D partnership with an SDARS satellite radio provider and an independent aviation company and/or university to evaluate the potential of providing weather information to NAS users via SDARS satellite broadcasts.

NASA should compare this approach with other commercial ventures for providing aviation weather for quality of weather information, timeliness, and value to the GA user.

Recommendation IV

- **Participate with FAA and RTCA in Safe Flight 21 and UAT R&D development**

Safe Flight 21 is a government and industry cooperative effort to develop Free Flight capabilities from evolving Communications, Navigation and Surveillance (CNS) technologies. Safe Flight 21 will demonstrate cockpit display of FIS including weather as well as traffic and terrain information for pilots. Traffic information will be realized by utilizing Global Positioning System (GPS) data and Automated Dependent Surveillance-Broadcast (ADS-B).

MITRE CAASD has developed an L-Band radio data link called the Universal Access Transceiver (UAT) for the FAA Safe Flight 21 implementation. UAT incorporates a broadcast architecture with two way transmissions. UAT ground stations can send FIS-B transmissions including weather as well as Traffic Information Services-Broadcast (TIS-B). RTCA SC-186 has drafted MOPS for UAT. MITRE has been flight testing UAT since 1995 with the assistance of the Florida Institute of Technology Aviation program and Embry-Riddle Aeronautical University.

FAA has conducted Safe Flight 21 demonstrations in the Ohio valley with the Cargo Airline Association (CAA) members (UPS, FedEx, and Airborne) as well as the Alaska Capstone tests with 100 to 200 GA aircraft equipped.

It is recommended that NASA join with FAA and RTCA in further development and evaluation of FIS-B weather services for GA. FAA is meeting with GA avionics manufacturers to discuss funding for GA avionics development. NASA can pursue their aviation safety mission goals and their CNS objectives while coordinating with FAA and participating in RTCA technical committees and work groups.

Recommendation V

- **Evaluate hybrid satellite and ground-based architecture**

The SAIC, ARINC, TRW and Crown Communications Weather Data link Architecture Study (May, 2000) [16] supported by NASA analyses concluded that a hybrid implementation of broadband satellite national broadcasts along with ground-based narrowband local broadcasts would be optimal for aviation FIS requirements. The results and conclusions obtained in this market survey and evaluation supports this assessment.

It is recommended that NASA evaluate this architecture approach by integrating a commercially available satellite broadcast service (PWA or Merlin) along with VHF (VDL-2/3) and/or UAT airborne receivers on a GA type aircraft. Data link integration of strategic and local weather data should be investigated. In addition, data link reception reliability in the presence of adverse weather and/or radio frequency interference should also be evaluated.

This R&D effort should be conducted in a context that future avionics must be multifunctional to provide maximum aviation services to the cockpit to enhance safety while minimizing space, weight and power requirements given the very stringent constraints within most GA aircraft.

AMA

Appendix One

Arthur R. Feinberg and James W. Tauss
Aviation Management Associates, Inc.
8752 Center Road, Springfield, Virginia 22152
Phone: 703-644-4465 Fax: 703 569 1577 www.avmgt.com

VENDOR SURVEY

Aviation Management Associates (AMA), a consulting firm located in Springfield, Virginia, has a NASA contract to conduct a market analysis of companies providing or intending to provide graphical weather information to the general aviation (GA) cockpit. The effectiveness of these commercial offerings to address pilot weather needs and improve safety are critical for NASA to determine future research investment decisions. Please answer these questions and provide any additional comments as appropriate.

Tell us a little about yourself and your company

1. Your name and title: _____
2. Company/Address: _____
   _____
3. Phone: _____ FAX:_____ Email:_____

Tell us about your Product Offering

1. Product name and Model #: _____
2. Product description/type (transceiver, MFD, etc.): _____
   _____
3. Additional H/W or S/W required: _____
   _____
4. Advertised product component costs: _____
5. Technological concerns and cost drivers: _____
   _____

Tell us about how the weather products are displayed

1. Cockpit weather display:_____
2. Additional product functionality:_____
3. Product/functionality growth capability:_____
   _____

Tell us about the weather services your product provides

1. Monthly costs and service plans: _____
   _____
2. Weather graphics included:_____
3. Weather text or other products included: _____
4. Weather product provider: _____
5. Product availability and response time: _____

Tell us how graphical weather products are received in the cockpit

1. Transmission media (cellular, satellite, etc): _____
2. Characteristics (request/response, broadcast, etc): _____
   _____
3. Receiver/antenna specific requirements: _____
4. Technological concerns/cost drivers:_____
   _____

Tell us about your ground infrastructure architecture

1. Distribution of weather products: _____
   _____
2. Interfaces with NWS, FAA, etc: _____
3. Communications network:_____
   _____
4. Technological concerns/cost drivers:_____
   _____

Tell us about product installation and integration

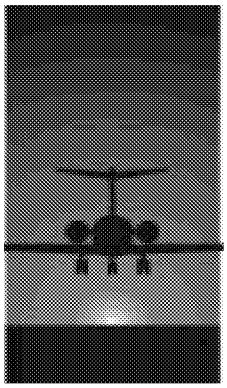
1. Product applicable to aircraft types:_____
   _____
2. Aircraft modifications:_____
3. Are products FAA certified/certification required? _____
4. Other compliance/integration issues:_____
5. Other compatibility/operational issues:_____

Tell us about your customers

1. Production quantity/unit sales:_____
2. Delivery lead time:_____
2. Reliability, Availability & Maintainability:_____
3. Warranty:_____
4. Target market & approach:_____
5. POC for Customer satisfaction/feedback: _____

Tell us some recommendations for improved market penetration

1. Cost drivers:_____
2. Barriers to market penetration:_____
3. Technological issues:_____
4. Suggested NASA R&D initiatives:_____
5. Additional comments & recommendations:_____
   _____
   _____



Appendix Two

Arthur R. Feinberg and James W. Tauss
Aviation Management Associates, Inc.
8752 Center Road, Springfield, Virginia 22152
Phone: 703-644-4465 Fax: 703 569 1577 www.avmgt.com

USER SURVEY

Aviation Management Associates (AMA), a consulting firm located in Springfield, Virginia, has a NASA contract to conduct a market analysis for the provision of graphical weather information to the general aviation (GA) cockpit. The effectiveness of these commercial offerings to address pilot weather needs and improve safety are critical for NASA to determine future research investment decisions. Please answer these questions and provide any additional comments as appropriate.

Tell us a little about yourself

1. Your name and address: _____
2. Phone: _____ FAX:_____ Email:_____
3. Type of aircraft you own_____
4. Where and how often do you fly_____

Tell us about how you receive graphical weather products in the cockpit

6. Product name/Model # (if known): _____
7. What other H/W or S/W did you need to purchase: _____
   _____
8. Were there any issues when installing:_____
   _____
9. Did you feel the cost to equip was reasonable:_____
10. If not, why:_____
11. Maintenance/Service issues:_____

Tell us about how the weather products are displayed

4. What graphical weather products do you receive:_____
5. What products do you NOT use: _____
6. Do you feel the cost is reasonable:_____
4. If not, why:_____

Tell us about the weather services you receive

6. Does the current service or functionality meet your expectations and if not why:_____
7. What are the required core capabilities: _____
8. What would you be willing to pay: _____
9. What would you like to see operationally approved:_____
10. Additional comments: _____

Appendix Three

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Glossary

ACARS	Aircraft Communications and Reporting System
AIM	Aeronautical or Airman's Information Manual
AEA	Aircraft Electronics Association
AGL	Above Ground Level
AMA	Aviation Management Associates
ANN	ARNAV Aeronautical Network
AOC	Airline Operating Center
AOPA	Aircraft Owners and Pilots Association
ASD	Aircraft Situation Display
ASIST	Aeronautics Safety Investment Strategy Team
ATC	Air Traffic Control
AvSP	Aviation Safety Program
AWIN	Aviation Weather Information
CAA	Cargo Airline Association
CDM	Collaborative Decision Making
CFIT	Controlled Flight Into Terrain
CSMA	Carrier Sense Multiple Access
CNS	Communication, Navigation, Surveillance
CPDLC	Controller Pilot Data Link Communication
CONUS	Conterminous United States
EAA	Experimental Aircraft Association
EFB	Electronic Flight Bag
FAA	Federal Aviation Administration
FCC	Federal Communications Commission
FIS-B	Flight Information System - Broadcast
FISDL	Flight Information System Data Link
FMS	Flight Management System
GA	General Aviation
GAMA	General Aviation Manufacturers
GEO	Geosynchronous Earth Orbiting
GMSK	Gaussian Minimum Shift Keying
GPS	Global Positioning System
GRC	Glenn Research Center
H/W	Hardware
IFR	Instrument Flight Rules
IMC	In Meteorological Conditions
LEO	Low-Earth Orbiting
METAR	Aviation Routine Weather Report
MFD	Multi-Functional Display
MNS	Mission Need Statement
MOPS	Minimum Operational Performance Standards
NAS	National Airspace System
NASA	**National Aeronautics and Space Administration**
NBAA	National Business Aircraft Association
NEXCOM	Next Generation Air/Ground Communication
NEXRAD	Next Generation Radar
NOTAM	Notice to Airmen

NTIA	National Telecommunications & Information Administration
NRC	National Research Council
NTSB	National Transportation Safety Board
NWS	National Weather Service
PC	Personal Computer
PDA	Personal Digital Assistant
PIREP	Pilot Report
R/R	Request/Reply
SDARS	Satellite Digital Audio Radio Systems
SOW	Statement of Work
STC	Special Type Certificate
SUA	Special Use Airspace
S/W	Software
TAF	Terminal Aerodrome Forecast
TBD	To Be Determined
TDMA	Time Division Multiple Access
TFR	Temporary Flight Restriction
TIS-B	Traffic Information Services - Broadcast
TOPS	Terrain Obstruction Proximity System
UAT	Universal Access Transceiver
UPS	United Parcel Service
VDL	VHF Data Link
VFR	Visual Flight Rules
VHF	Very High Frequency
WINCOMM	Weather Information Communications
WxAP	Weather Accident Prevention Project

Appendix Four

Vendor	Product Description	Weather Display	Data Link Characteristics	Weather Data Source/Prods.	NR Cost	Rec Cost	A/C Type	Technical Considerations
Aircell, Inc. Louisville, Colorado www.aircell.com	Airborne cellular systems, A/C installed Guardian 1000, AT.02, AGT.02	Flight Guardian S/W on MFDs, PDA's, Laptops	Ground based, U.S. cell towers, voice and data. R/R, 9.6kbps	Meteorlogix, DTC Duats NEXRAD, FIS data	$4 - 8K	$30 - $499/mo. (voice) plus $2/min	Piston (Guardian) and jets or turbo props (AT or AGT.02)	LOS issues (>5000' AGL) Voice and data, CONUS coverage FAA certified (STC's)
UPS Aviation Salem, Oregon www.upsat.com	MFD MX-20	S/W to interface with both Aircell (Guardian) and Satellite Tech.(Merlin)	Aircell: Ground based cell tower network, Merlin: Geosync. Satellite	Aircell: Meteorologix, Merlin: Jeppesen Products TBD	$7.3K	TBD		Aircell: same as above. Merlin: Antenna, cost, avail.?
Echo Flight Boulder, Colorado www.echoflight.com	EchoMap S/W and satellite transceiver communicator. A/C installed avionics system	Laptop Flight Cheetah MFD Garmin 400/500 MFD	LEO (Orbcomm VHF) satellites, 2-way data link, R/R, 57.6kbps	Meteorlogix Composite NEXRAD, ceil./vis., precip. Wind speed/dir., T/Td, METARs, Graphic METARs.	Cost of laptop $6k $2K	$9-55/mo. plus $1 each access		Global w/US weather data. No TAFs. Displays (Echo & Garmin) Portable w/GPS (no FAA certification)
ARNAV Puyallup, WA www.arnav.com	WxLink VHF receiver (DR-100) and WxNet transceiver	MFD-5200, ICDS MFD	VHF Towers, FIS GMSK, broadcast, 31.5kbps	Meteorlogix METAR text, graphical surface conds.. Premuim products: NEXRAD composite, winds aloft, SIG. WX reports inc. 3-D turb., icing, graphical METARs, NCWF	$8 - 10K	$42/mo. for premium graphics	Most	LOS issues. Not nationwide. FAA certified products. Can be used with several other MFD manufacturers.
Honeywell Bendix/King Olathe, Kansas www.bendixking.com	KDR 510 receiver	KMD-550 or 850 MFD system	VHF Towers, FIS VDL-Mode 2, broadcast, 31.5kbps	NWS (NOAAPORT/AWC) METAR and TAF text, AWW, PIREPs, AIMETS/SIGMETS., CONV. SIGMETS. Premium products: Regional and national NEXRAD w/animation, 0.5 BREF, graphical METARs, NLDN	$7.5-12.5K	$49/mo. for premium graphics	Lower end GA up to biz. Jets	Currently 39 towers implemented (east of Miss.) Mid 2003 200 towers for full CONUS coverage. FAA LOS issues (>5000' AGL)
WSI Corp. Billerica, MA www.wsicorp.com	WeatherStream's Pilot Weather Advisior (PWA)	Variety of MFD's and portable devices inc. EFB's (planned)	GEO Satellite, broadcast	WSI Products TBD	$5K (est.)	$30-50/mo. (est.)		Western Hemisphere Data only Late 2002

Appendix Four.—Concluded.

Vendor	Product Description	Weather Display	Data Link Characteristics	Weather Data Source/Prods	NR Cost	Rec Cost	A/C Type	Technical Considerations
Jeppesen Engelwood, CO www.jeppesen.com	Flight Star	Eflight Pad (Intermec), Laptop or other MFD's	Aircell: Ground based cell tower network, Merlin: Geosync. Satellite	DTC/Dyncorp DUATS, Jeppesen DUATS text, NEXRAD composites, winds aloft, icing, SIG WX progs, surface anal., wind/temp. forecasts.	$4.5-5K	$19.95/mo.	Most	Aircell service current, Merlin planned mid 2002 FAA certification unknown
Rockwell Collins Cedar Rapids, IA www.rockwellcollins.com	Communication Management Unit and Radio Interface Unit, file server	Adaptive Flight Display 3010E	VDL-Mode 2 (land), Immarsat (ocean), ACARS protocol	Universal Weather Graphical worldwide weather, NEXRAD	$50K	$400-1,300/Mo.	High end but used down to Premier CJ's type certified in '03 for Challenger 601	Considering forey into lower end GA market with potential leveraging of ARINC infrastructure
Avidyne Lincoln, MA www.avidyne.com	FlightMax DX50 transceiver	FlightMax MFD (EX5000)	LEO (Orbcomm), R/R, digital 2-way VHF format	Wx. provider TBD TBD but national and regional NEXRAD mosaics, METAR (graphical and text) planned	$2,950 for tranceiver, $10-18K for MFD	$29-49/Mo.	Panel mounted for Part 23	Only CONUS FAA certification pending
ControlVision Pittsburgh, KS www.anywhereus.com	Anywhere WX, GPS flight manager S/W	Compaq IPAQ PDA	Aircell: Ground based cell tower network, LEO (GlobalStar) satellite, R/R	Meteorologix NEXRAD mosaics, METAR and TAF	$2,899	$30-100/Mo. Plus $1.75/min.	Cessna 175, other private	Not IFR certified
Flytimer Concord, MA www.flytimer.com	ACARS Control Unit Transceiver	MFD's, IPAQ, laptop	ARINC ACARS network, R/R	NEXRAD, METAR, TAF, TAMDAR products planned	TBD	TBD	Low end GA	Digital ATIS and email also available Auto-tunable to take advantage of excess side bandwidth TAMDAR probe to be integrated Certification planned this year. Live flight trials planned
Garmin Olathe, KS www.garmin.com	GDL 49 Transceiver	MFD's (GNS 430, GNS 530)	LEO (Orbcomm), R/R, 2.4kbps uplink and 4.8 kbps downlink	Meteorologix via Echo Flight data-link service NEXRAD, graphical and text METAR and TAF	$3,495 for GL 49	$9.95-55/Mo. Plus $1 each access		
Satellite Technologies, Inc. Dulles, Virginia www.satellitetech.com	MA SK-1 satellite receiver	Merlin system dispays on various MFDs	GEO satellite, broadcast	Jeppesen GOES IR images, composite satellite, NEXRAD 0.5 BREF, NEXRAD Echo Tops, SIGMET, CONV. SIGMET, Icing reps., Wind/temp aloft fcsts., METAR, TAF, AIRMET, PIREP, TFR, ASD, various NOTAM, Flight Explorer service	$3.5K	$45/mo. After year 1.		MA SK-1 certification by FAA pending Data only

Appendix Five

Company, Address, Phone, Email	Contact	Product and Description	Non Recurring Cost	Service Plans and Recurring Costs	Availability	Weather Source, POC and Email	Comm. Link	Req. Equipage	Maintenance or Warranty	Applicable Aircraft, Mounting, Power	Constraints or Considerations
AirCell, Inc.	Brian Ozz, Director of New Technology Direct Number ~ 303.379.0239 FAX ~ 303.379.0201 . Alternate POC is Bill Dardac, Technician Sales, and Marketing at 913.780.3488	Guardian 1000. Airborne cellular transceiver, panel mounted system provides voice, data, and battery back up comms. Data can be displayed on MFD's, PDA's or laptops. 911 service.	Around $3,500 uninstalled. SAV is $99.95 for Compaq iPAQ PDA. Otherwise $649.95 for the SAV and PDA.	$9.95/month plus $1.99/minute for data services alone (Flight Guardian); $29.95/month up to $499.95/month plus $1.99 - $1.75/minute for voice and data (various levels of service with minutes included). Additional charge for weather. Access to FIS data including NEXRAD images. Additional $10/month for wx access using other H/W or SAV.	Current - Wx availability announced at Sun N Fun (April 2002). Guardian 1000 just released - in production. 350 dealers (i.e., Duncan Aviation)	Use Flight Guardian SAV. MeteoInsight is the weather provider. Also DTC DUATS available.	Ground-based cellular telephone network (voice and data). Used existing towers (leased space) with antenna dish forward up. Very low power. Continental US coverage. In-House Mulnt: 90% of all voice calls successful 1st time; 70% of all data transfers successful 1st time.	Transceiver unit, antenna. Need a display device. For use with Anywhere Wx (Control Vision planned capability), need the moving map SAV for geo-located refectivity (Available summer 2002)	Specific maintenance plan on back of service agreement. Some have Guardian 1000 has 1 year limited coverage, AT.02 has 2 year limited coverage. Broken equipage is sent directly back to Aircell.	Designed specifically for piston aircraft. Certified up to 250 Kts (antenna). Guardian Transceiver unit is 8.5" L x 6.25" W x 1.25" H. Max power 18-32 VAC.	Line of site issues. Typically starts above 5,000 feet AGL in many areas. Waist. Plan on back of service agreement. Only pay for link when data going through (RR by the minute). Transport of the data to the cockpit is where the cost is - not the data. Flexibility is there to add more channels. 2K-25Kbyte files downloaded in about a minute. DataComm will become available as a data only solution when integrated SAV matures for display on other MFD's. Graphical weather is stand-alone with no aircraft proximity integration. No other overlay capabilities.
1172 Century Drive Suite 260, Building B Louisville, Colorado 80027	303.379.0200	DataComm 500. Airborne data transceiver. Data and listening only capability. Data can be displayed on MFD's, PDA's or laptops. Included the voice receiver.	$2K uninstalled but not currently on the market as a stand-alone module due mainly to overwhelming interest in Guardian 1000 and the fact that DataComm has no tactile display to show strength of signal.	$9.95/month plus $1.99/minute for data services alone (Flight Guardian); $29.95/month plus $1.99/minute for data (Flight Guardian Plus). Also provides ATIS and AWOS voice channels. Internet connectivity, email. Vanity # voice receiver is an additional 1x cost. Additional $10/month for wx access using other H/W or SAV.				Transceiver unit, antenna. Need a display device. Flight Guardian Plus also requires MX-20 or H/W and SAV from other companies (Working with UPS Aviation Technologies for example)			
[redacted]		AT.02. Airborne voice and data transceiver. Contains internal modem and RS-232 port. Connects to MFD's, PDA's, and laptops. Intercom functionality.	Around $4K uninstalled	$9.95/month plus $1.99/minute for data services alone (Flight Guardian); $29.95/month up to $499.95/month plus $1.99 - $1.75/minute for voice and data (various levels of service with minutes included). Additional charge for weather. Access to FIS data including NEXRAD images				Transceiver unit, AMU kit, connector, antenna	2 year	Certified for jets and turbo-props up to 600 Kts (antenna). Piston pleas too loud for voice function.	Line of site issues. 6-month free intro airtime package
		AGT.02. Air/Ground voice and data transceiver for use on ramp or in air. Includes 2 phone modules, internal modem, and RS-232 port. Can connect to MFD's, PDA's, and laptops. Intercom functionality.	Around $8K uninstalled	$9.95/month plus $1.99/minute for data services alone (Flight Guardian); $29.95/month up to $499.95/month plus $1.99 - $1.75/minute for voice and data (various levels of service with minutes included). Additional charge for weather. Access to FIS data including NEXRAD images							

Appendix Five.—Continued.

Company, Address, Phone, Email	Contact	Product and Description	Non Recurring Cost	Service Plans and Recurring Costs	Availability	Weather Source, POC, and Email	Comm Link	Req. Equipage	Maintenance or Warranty	Applicable Aircraft, Mounting, Power	Comments or Considerations
UPS Aviation Technologies	Jim Guffeau, Head of Sales	MX20 - Multi-Functional Display	$7,295.00	Not available yet	SW to interface with Aircell and Satellite Technologies proposed mid summer 2002	Aircell source is Meteorologix Satellite Technologies (Merlin) source is Jeppesen.	Aircell would be cellular ground stations. Merlin service would be via GEO.	SW to interface is in addition to MFD. Different antennas likely based on which service desired.		MX20 has a 6" diagonal screen. 640x480 pixels. 10-40 VDC max power.	Cost for Merlin service/equipage likely to be more. NOTE: Also working with Bendix/King to develop interface to receive data/wx weather info via FIS-B. Status unknown.
2365 Turner Road SE, Salem OR 97302	800 525 6726										
www.ups.com											
Echo Flight	Cindy Smith	EchoMap SW and satellite communicator. Communicator uses GPS for navigation and two-way messaging via Orbcomm network. Data is sent through RS-232 serial port and can work on laptop loaded with EchoMap. NOTE: Data only	Cost of laptop plus EchoMap SW and transceiver at $1,795 and antenna at $180.	Generally from $9.95/month to $65/month plus $1 each access. Package deal of $29.95/month includes free weather images every 20 minutes. $1.00 for additional images at higher hourly frequency. Weather products include composite NEXRAD, ceiling and visibility, precipitation, wind speed and direction, temperature and dew point spreads, email and position reporting. METARS and Graphic METARS available but no TAFs.	Current. U.S. wx data available worldwide.	Meteologix (formerly DTN)	Orbcomm LLC's low Earth-orbit communication satellites on VHF frequency. Downlink is 137-138MHz or 400MHz. Uplink is 148-150MHz. Although R/R, can set up download intervals every 15, 30, etc. minutes - as quasi-broadcast. Takes 2-2 1/2 minutes from request to receive products. 2.4kbps up link and 4.8 kbps downlink. Claim is that this is adequate because of their compression and burst transmission mode techniques (metric of 96% of messages within 20 minutes via this technique).	Laptop PC with RS-232 port, cable, Antenna (non-directional)	30 day money back. S/W upgrades included with monthly subscriptions		Requires EchoMap SW and Orbcomm communicator. According to EchoFlight - will not get FAA certification because it is portable. 6.4" diagonal display screen for the PC-270. 10-35 volts power.
1919 14th St., Suite 601, Boulder, CO 80302 888 739 7161	Sales: 888 948 9667	Flight Cheetah f270. A MFD with a modified display screen to reduce glare, increase brightness. Data only but can include Navaid DB, Digital Approach Chart subscription, WAC's, etc.	$5,995 for Flight Cheetah turnkey package (inc. both GPS and VHF antenna, S/W and transceiver)					Flight Cheetah. Mounting hardware.			Pricey. But data access anywhere, request-reply, email possible. Better image quality over laptop esp. glare reduction. NOTE: Flight Cheetah f 80 not available yet (smaller version of the 270). MFD allows animation for friend. Enhanced mapping functionality is better than terrain alert to overlay with weather refractivity mosaics due to similar colors. No traffic info. Graphical weather can be overlaid with approach graphic.
www.echoflight.com	sales@echoflight.com	EchoMap S/W and transceiver used with Garmin GNS 400 and 500 series MFD's. Data only	Cost of Garmin avionics plus S/W and transceiver at $1,795					Garmin avionics, EchoMap S/W and Communicator. Vanity need for mounting hardware			Recommendation to NASA is to make the data link free. EchoFlight makes their money on the H/W and S/W they sell.
Satellite Technologies Inc.	Harlan Hordin, VP and Chief Aviation Services. Cell phone is 571 233 5058. Craig Cortese and Joe Bowman also support Harlan.	MA SK-1 satellite receiver.	MA SK-1 will be priced at $3,500 and does not include an MFD or other display device. This includes 1 full year of weather data link Merlin Service and using the Apollo UPS-AT display.	Fixed monthly service estimated to be $45/month after the first year for unlimited access to GOES Infrared, visible, composite satellite, NEXRAD 2km base ref., NEXRAD echo tops, Conv. SIGMETS, SIGMETs, long expo., turb. Reps, wind and temp aloft fests., METARs, TAFs, AIRMETs, PIREPs, Temporary Flight Restrictions, Airspace Situation Displays, Airway NOTAMs, Facility NOTAMs, NAS NOTAMs. Flight Explorer service will also be made available (verify if additional charge)	Summer 2002 launch	Jeppesen Data Plan	Broadcast via GEO., Mobile Satellite Ventures (MSV). (Formed partnership with TMI communications and Motient Corp (formerly AMSC)). L-Band transmission.	Merlin-Air portable service kit includes the receiver (Model MA SK-1) with integral GPS receiver, FAA certified antenna, and interface S/W to the display device. Display device and interface cable not included. Display devices required include PDA's, panel mounted MFDs, Laptops or PCs. Display device needs a standard USB or RS-232 serial port.			MPR-1 certification by FAA to be obtained after MA SK-1 in production and commercially available. This will allow Merlin data to be displayed on FAA certified equipment. Recommendations include shorter certification time and development of future industry display standards without any near term impacts to daley customer acceptance. Discussed a "consumers report" type of flight test evaluation by NASA or Emory Riddle of all current product offerings. Suggested NASA to assess market price sensitivity for weather in the cockpit (what will GA pay?). Liability issues/cost for these aviation products into a concern. At Sun N Fun they will be demonstrating the Merlin service at several booths - Jeppesen (who also does Flight Map and Flight Deck), UPS Aviation Technology, EDMO (worlds largest avionics distributor), Eastern Avionics, Ioanis Instruments (IFAC product), Blue Mountain Technology (home-built market), Sellers Aviation (PC Flight Systems), and Lance Air Avionics (Kit planes).
21700 Atlantic Blvd., Dulles, VA 20166	703 758 7010					Mike Gehrich mike.gehrich@jeppesen.com					
www.satellitetechnology.com	703 575 4061	www.satellitetechnology.com				www.jeppesen.com					
Weather Services International	Keith D. Hoffler	Pilot Weather Advisor (PWA). Offers graphic and text weather on a wide variety of PC's and CPU-based displays via an RS-232 interface. The receiver is a blind mounted satellite receiver system	Between $4-6K for the hardware (current quote in AOPA mag. 3/25).	Less than $60/month. Subscription and flat fee programs planned. Cost driver for relatively low subscription fee quoted as competition. Additional features and option planned	Sandia certification planned for late fall 2002 with shipments to customers shortly thereafter	WSI	GEO continuous broadcast via Mobile Satellite Ventures (MSV). (Formed partnership with TMI communications and Motient Corp (formerly AMSC))	Remote mounted receiver and antenna. Outside manufacturers of MFD's not identified as of early March 2002 - but working to form strategic partnerships including Avidyne, Goodrich, Honeywell, and USPAT.		Initial installation in a Piper Saratoga. Other aircraft to follow to facilitate certification. Sandia display to be made appropriate for all aircraft.	Uses quality WSI data - in FSS, all top 50 FBO's, etc. 5-minute update cycle - no data more than 11 minutes old. 3 marketing strategies planned. Work with MFD manufacturers, stand alone system, and interface with portable electronic flight bags. Runs on Windows 98, Me, XP, etc. PWS developed under NASA SBIR contracts including phase III from NASA GRC (WINCOMM). Recommends timely TFR and NOTAM info. METARs every 5 minutes. Consumer Reports type testing welcome if objective (Aviation Consumer Mag?).
4 Federal Street, Billerica, MA 01821	757 865 1400 x221	SW that can be used with Northstar avionics, ADR Flightguide, and eflightpad (3 different flight bags)	Northstar ($12K), ADR Flightguide ($7K), Eflightpad ($6K). Investigating IFAQ PDA. Recent WSI announcement indicates strategic partnership formed with Sandia Aerospace to produce avionics.								
www.wxsvcs.com	hoffler@wxsvcs.com	www.wxsvcs.com									

Appendix Five.—Continued.

Company, Address, Phone Email	Contact	Product and Description	Non-Recurring Cost	Service Plans and Recurring Costs	Availability	Weather Source, POC, and Email	Comm. Link	Req. Equipage	Maintenance or Warranty	Applicable Aircraft Modeling, Power	Constraints or Considerations
Garmin	Sales = Scott Smith, Technical = George Kraetsch. Sheryl Millsap, Aviation Desk. Best info is on web site.	GDL 49 Datalink Transceiver add on to the GNS 430 or GNS 530 MFD avionics. Lightning and traffic data already available. GNS 430 combines GPS navigation, VHF comms., and moving map graphics. Also includes IFR GPS, ILS, VOR, LOC and glideslope. WAAS compatible. GNS 530 display is larger and has additional functionality.	$3,495 for the transceiver	From $9.95/month to $65/month plus $1 each access. Access to NEXRAD, text and graphical METARs and TAFs.	Literature states late 2001 but FAA approval of EchoFlight product likely in late April 2002	Meteorlogix (formerly DTN)	Orbcomm LLC's low Earth-orbit communication satellites	Purchase of the GDL datalink transceiver and EchoFlight SW assuming already equipped with GNS 400 or 500 series MFD avionics	1 year limited	GDL 49 transceiver: 9" L x 5.4" W x 2.1" H. 6-31 Watts max power. Horizontal or vertical mounting. 410 series: 3.75" diagonal LC display; 11-33 VDC power. 500 series: 4.75" diagonal LC display; 11-33 VDC power.	Requires EchoMap SW and Orbcomm communicator. NOTE: EchoFlight product not FAA approved yet (Planned launch 4/20). Must contact local dealers for references. Scott Smith recommended Penn Avionics in Collegeville, PA 610 409/0328 ext. 4. Ask for Peter Stalbaum/ruler.
1200 E. 151st. Street, Olathe, KS 66062	913 397 8200										
www.garmin.com	Go to web site, type in dealer location, aviation, VA to get dealerships										
Avidyne Corp.	Jason Och. New biz development and product manager 781 402 7476. He is the person to discuss cost drivers and related issues. Mark Sandeen is Jason's boss. jochfaa@avidyne.com	FlightMax D950 datalink transceiver. MFD is Flight Max with either 5" or 10.4" EX5000 display	$2,950 for the transceiver includes antenna ($2,450 for existing customers). Requires an Avidyne MFD (Flight Max series). For example, the EX5000 is about $12,950. Other MFDs range from $10-18K. Stand alone, remote mounting, VHF compatible.	About $399/year (30 updates/month); or $349/year (10 updates/month). Plan to include NEXRAD national and regional mosaics for CONUS, graphical SIGMETS, plan text METAR, No TAFS yet.	Mid-late 2002	Wx provider not announced yet	Orbcomm LLC's low Earth-orbit communication satellites. R/R. Digital format, 2 channels (2-way VHF in the 137-138 uplink and 150 downlink mghz). Only CONUS currently available. Ground stations to send/receive messages. 2-7 minute typical response time.	Use with FlightMax FSD products (ex. FlightMax EX5000)	Not announced yet but 2 years parts and labor likely.	Panel mounted for Part 23 aircraft - up to King Air (basically multi-engine). They claim about 2000 users but no evidence. 320x234 pixels x 65,536 colors. 5" diagonal color active matrix LCD. 10.4" diagonal for EX5000 with 800x600 pixels and 65,536 colors.	FlightMax designed to interface with FlightMax flight MFD's ONLY. Bi-directional Request-Reply
66 Old Bedford Road, Lincoln, MA 01773	781 402 7585										Working FAA certification. Not releasing production estimates
www.avidyne.com	800 284 3963										FIS are aviation-epacific networks. Suggestion is to leverage technologies already developed - now diffusent technologies going head to head, but no interoperability. Need higher level of integration to combine solutions. Otherwise market can only support so much. **Combination transceivers that can handle multiple technologies** - Lower end GA solutions probably not an option due to costs alone. Need to compel folks here to equip via regulatory or for compatibility (if FAA goes digital). Consider spectrum management. Ultimately broadcasts are good for common data but 2-way or msg capability gap.
ControlVision	Link up with Richard Herbst, Marketing. References and sales brochures (including maintenance and weather source) being mailed to AMA. Alan Kirby, Tech. Specialist was very helpful. Number is 620 231 9748.	AnywhereWx is an integrated GPS Flight Manager SW, that can received data link weather via either a satellite link (Global Star) or cellular (AirCell)	$2,899 introductory offer includes Compaq IPAQ PDA, GPS receiver, AnywhereWx SW, Global Star GSP 1600 Tri-satellite phone, and universal yoke mount. Weather upgrade only is $1,699. Can also be used with AirCell's Guardian 1000 at $3,500.	$30 - $110/month plus $1.49-1.69/minute. Includes national radar, NEXRAD, and METAR and TAF text. Retail dictated by number of free minutes. Download upgrades to computer via Internet. 6 Month free upgrades w/purchase then $119/year for 12 upgrades (Airways, airports, etc). TFRs updated daily but need phone to dial up sat. phone Internet connection.	Current - weather service since 1/1/02. about 400 users. Otherwise about 6,000 registered users.	Metecrologix	Global Star satellite telephone or AirCell Ground based cellular network.	Compaq iPAQ, Globalstar tri-mode phone, AnywhereWx SW, GPS receiver. Sell-pack integration module, mount. Need an expansion sleeve card to attach to PDA to have a wireless modem.	6 Month limited for HW. Phone and IPAQ separate.	Cessna 175, other priarts. Uses Aircell Guardian 1000 transceiver (dimensions and power apply).	Average download time is 30 seconds between request and receipt of weather info. Comm is dropped after 1 minute. Cellular solution is R/R. Global Star used for making calls (no cell phone use in cockpit). Can the wx piggy back on the cell phone use? With 1 minute drop of comms from Global Star, would not have inappropriate use of phone time when metred towers. Not IFR certified. S/W runs on Pocket PC or Windows CE. Aircell provided wx graphics can be displayed on moving map with flight plan, traffic, and terrain. IPAQ display considerably smaller than average MFD.
Box 596, Pittsburgh, Kansas 66762	620 231 6647 alan@anywharemap.com										
www.controlvision.com	800 292 1160										
Arnav	Frank Williams (President), John Gleeyer, Program Manager FISDL. Spoke at length with Susan Hammer, VP, 253 848 6060 x28 shammer@arnav.com	WxLink receiver and WxNet transceiver are high speed, multimode, multifrequency datalink. MFD 6200 (lower-end). ICDS 2000 higher-end). DR-100 aircraft datalink receiver. ROCM-100 SatPhone@$19,995.	MFD 6200 around $6K. Paired with the DR-100 costs $9K. ICDS around $16K.	Free transmission of FIS, METAR, text and graphical surface condition reports. Premium products to be available at additional cost ($495/year) include NEXRAD composite graphics ($4/sq national mosaic within 150nm from the aircraft and 6km local mosaic within 150nm from the aircraft), winds aloft graphics, and significant weather reports including 3-D turbulence and icing graphics, graphical METARs, NOWF-1 hour products.	Current but unknown as to status of full CONUS implementation. Claimed availability in small regions of the country.	DTN Meteorologix	Selected by FAA along with Honeywell to provide weather data link service via FAA provided spectrum. Currently using VHF SMSK but started to switch to VDL-Mode 2 by 2004. Product is called WxLink which periodically broadcasts wx info to the cockpit while in flight using the WxLink receiver and WxNet transceiver. 2 VHF frequencies to broadcast over a portion of the ARNAV Aeronautical Network (AAN). Also has a partnership with Global Star to provide voice and data to cockpit via LEO constellation.	Wx Data link SW, MFD 6200 Cockpit display, DR-100 aircraft data link receiver, engine monitoring module, antenna?			Applicable to most aircraft. About 200 E-sales. MFD 6200 CDU max power 25 Watts; 5" diagonal LCD. ICDS max power 50 Watts; 10.4" diagonal LCD.	FAA Certified products. Suggested NASA R&D initiatives mentioned were E-PIREPs. Additional product tracking capability (ADS-B). Other MFD's that can be used with the DR-100 include Sammi, Allied Signal, Trimble, II Morrow, and North Star. Graphical weather can be overlaid with Terrain Obscuration, Proximity System (TOPS). Some TOPS icons are the same color as heavy convective reflectivity colors so unclear as to how displayed when overlapped
www.arnav.com											

Appendix Five.—Concluded.

Company, Address, Phone, Email	Contact	Product and Description	Non-Recurring Cost	Service Plans and Recurring Costs	Availability	Weather Source, POC and Email	Comm. Link	Req. Equipage	Maintenance or Warranty	Applicable Aircraft, Mounting, Power	Constraints or Considerations
Honeywell Bendix/King	Gary Shutsville – 913 712 5545 Gary would be the person to talk to cost drivers and the like. Dustin Wandler, also 913 712 5766 to send out brochures on AFIS, FSDL, and KDR equipment. Tom Kraft is the marketing manager for Integrated Hazard Avoidance.	KDR 510 VDL-Mode 2 datalink receiver	$5,495 for datalink receiver only - to be integrated with the 550 or 850 MFD System. Price includes the interface module card (KAC 503 FIS module). Antenna not included. KMD550 is $7,460 (non-radar equipped aircraft) and the KMD850 is $12,495 (radar equipped aircraft).	Free products include text TAFs, METARs, SPECIs, AWW, PIREPs, AIRMETS and SIGMETs, CONV. SIGMETs. Broadcast data available to anyone that can receive it today. Encryption starts early '03. Value-added graphics at $4/6/month/ with yearly contract. Includes NEXRAD (regional and national at 4Km resolution, animation available early '03, graphical METARs, NLDN	Current but full NEXRAD coverage east of the Rockies by May 1, 2002. Mid 2003 for full coverage anticipated. Sales person said the ground system is quite reliable since they store and buffer. 50 out of 200+ towers installed as of mid June 2002.	NWS	Weather is broadcast via Honeywell proprietary ground stations (approx. 220) with data formatted for Bendix/King receivers. Uses FAA provided spectrum. KDR datalink receiver uses VDL-mode 2 at 31.5Kbps.	KDR 510 VDL Mode 2 data link receiver, KAC 503 FIS module, dedicated VHF antenna. The FIS module can be installed on the KMD 550 or KMD 850 MFD's	2 years.	Lower end GA up to some biz jets. Several hundred sales. Direct marketing. KDL 510 transceiver is 3" L x 6" W x 10" H, 10-32 VDC max power. Horizontal or vertical mounting. KMD 550/850 has a 6" diagonal with 10-33 VDC max power.	Line of site but available above 5,000 feet. Any older equipment will have to be upgraded to the KMD 550 or 850. The HAS 5000 and 8000 are total systems that integrate the KMD functionality to bring positioning, weather, avoidance, traffic advisories, and terrain warnings. AOPA spokesman said that this integration was the way to go but expressed concern that the price was way too high for weekend warriors. Can overlap weather with flight plan and traffic. If equipped with on board radar, can display electrical discharge with NEXRAD.
One Technology Center, 23600 W. 105th St., M/D #46, Olathe, KS 66061-1960	877 712 2386 gary.shutsville@honeywell.com	AFIS	Much higher price but geared towards very high end biz jets and commercial carriers (esp. who travel out of US)		Worldwide coverage					Larger biz jets, corporate and commercial carriers	Ground and satellite based so availability is worldwide. Price and capability is compatible and competitive with Teledyne's Telelink, Universal Avionics Unilink, and Rockwell Collins AFD 3016E system. Leverages ACARS infrastructure.
2601 0000 0000 2601	913 712 2613										
Rockwell Collins	Matt Smith - Manager of Advanced Products 319 295 7290	NOTE: Not for low-end GA	In the $50K range for business/regional/jet applications (not the more expensive 900 series which is made for Air Transport). Breakout is: VHF radio 4000 at/ort $14-18K; CMU about $25K; Upgrade of CDU or display to receive graphical weather about $10K. Additional File Server Unit is about $30K.	Graphical worldwide weather including overlays for NEXRAD products. In the $5-15K/year range.	Type certified for Challenger 601 by Summer '03	Universal Weather	VDL-Mode 2 ACARS/ARINC network over land or SatCom over ocean (Inmarsat). 25KHz channels. 31.5kbps. RR			Currently strategizing how to support this market. Would like to leverage ARINC infrastructure.	
400 Collins Road, NE., Cedar Rapids, IA 52498	319 295 1690 mtsmith@rockwellcollins.com	Communication Management Unit (CMU) MODEM, Radio Interface Unit (RIU). Not ATM compatible yet. Gel text and graphical products from the CMU on a dumb display called the CDU 739 using ACARS protocol. Also CMU can interface with a file server unit to show graphical products on a heads up display called an Adaptive Flight Display 3016E								Current offering geared towards very high end users but the 3016E heads up display is used down to Premier CJ's. Also used in King Air and Part 25 Citations.	Recurring comm costs about $500/month. VHF has coverage issues (LOS); need to be at altitude to access info. Need low cost SATCom like GPS - not privatized. Complex at the product level.
www.rockwellcollins.com	brad.beadle.ce@rockwellcollins.com										FIS-B still has questions in his eye- like broken up into regions and flight plan has to go through more than one. Data can be 'stale' because data stored on board. But they are looking at it and plan to be compatible. VHF (VDL Mode 2 R/R) comms as listed here does not have the ARINC-600 connection. This is priced considerably higher (about $200K) and is more rugged for Air Transport applications.
Goodrich	Ray Walker	SkyBlock II is under development and will be an integrated Flight Display and Control System that will allow data link of graphical weather. Otherwise only Stormscope which displays electric discharges from a cone-mounted sensor (not data link). Discharges from the stormscope can also be displayed on Garmin	TBD	TBD	Sometime in 2003	TBD	Data link and weather provider evaluation ongoing. Possible announcement by Oshkosh (July 2002). Looking at a GEO broadcast data link.				Issues: they are working on include how to get around subscription costs (especially for those that don't fly 6 months out of the year). This indicates they want to target, in part, lower-end GA users. Also they would like NASA to encourage growth/marketability to bring costs down and to reduce certification time (process). Many times there are second thoughts to adding functionality due to time to cert. issues.
Goodrich Avionics Systems 5353 52nd. St., SE, Grand Rapids, MI 49512-9704	937 426 1700X3012										
616 949 6600	www.goodrichavionics.com										
Flytimer	Stan Duttacher, CEO	Transceiver with generic RS-232 connection (an ACARS Control Unit) that hooks into a MFD, IPAQ, laptop, etc. 3 offerings are being planned: simple piston GA, higher up, and jets. Auto-tunable to fit into excess bandwidth (slices of baseband). Basically a reseller of ACARS services.	Approximately $2,500 (transceiver, antenna and SAW) for lower end; $4,500 for mid level and $6,500 for high end	Recurring subscription costs TBD but competitive. Expected to include graphics and text products including NEXRAD (every 15 minutes as available) and GAI lightning data. Dispatch of logistics services, tie into ARINC, email, digital ATIS, pre-dep. clearances also.	Product rollout 4th quarter '02.	TBD but looking at various NIDS vendors	ARINC/ACARS network with processing power on the ground. RR to convert text of graphics. Developing an encoder to compress weather images to send over slow network. 2.4kbps up to plane. They feel that this is sufficient for graphical weather data (352 towers and 9 frequencies for use). Plan to upgrade to VDL Mode2 with ACARS certification by late summer '02.	SAW pushbase, transceiver, display device or S/W for your MFD. Final application layer to be developed.			Simple piston GA all the way up to biz jets	Certification: STC on jets, twin - 337 form, portable electronic - none but expected 3rd quarter. Prototype currently 'flying'. UAT is threatened by ACARS and Flytimer dispatched from FAA initiative due to 'spurious' seasons (UAT lag, for broadcast between airplanes... Flytimer doesn't broadcast past to pilot). NOTE: TAMDAR (Tropospheric Atmosphere Meteorological Data and Reporting) optical detection system demonstrated - Auto PIREPS (senses 9 parameters and sends to ground based towers with 3-D time stamp). Probe to be integrated with Flytimer system
Concord, MA	www.flytimer.com										
978 318 06007224	ceo@flytimer.com										
Universal Avionics	Paul Tews, Program Manager for Multifunctional Displays. David Upchurch, Marketing. Sales for the east region are Tom Hook at 410 356 2769 and Randy Chappell at 860 824 0319.	UniLink. Can be configured to act like a modem (telephone) or VHF transceiver. UniLink LS is an accessory to their Flight Management System (FMS) called Flight-Deck Connect.	Approximately $28K for the VHF transceiver (not including installation and standardized antenna). Approximately $20K for the modum unit (no VHF transceiver). NOTE: Either configuration requires FMS for GPS navigation. Approximate minimum equipage cost is $35K.	VHF: technical receipt of ARINC type messages only as well as flight plans, position reports,etc. Graphics and text received from UniLink modem include NEXRAD mosaics, satellite imagery (vis. and IR), winds aloft, taps/movement, other AWC-derived graphics. Looking at pre-pay type of service per packet level of use) for low-end part time/volume/occasional users.	Current service.	Universal Weather - Brian Allen in Houston, TX. 800 231 5600	ACARS, airborne phone (ground based commercial VHF). VHF is about 600 kbps range (12 lines of text). Telephone is about 2.4kbps range for graphics.			Biz jets. Higher end turbo props including King Air and Gulfstream	Regulatory issues such as FIMS is for level C, 178 issues
3260 E. Universal Way, Tucson, AZ 85706	520 295 2300										
www.universalavionics.com											
Jeppesen	Matthew Rowe, Marketing Rep. For Navigation SAW, GA Division	FlightMap SAW includes FlightStar. For North America coverage. $499/ ea charge. In-Flight SAW to be released with Sat Link (pocket optimized interface). Need Aircell phone.	Table computers @ $4-6K with wireless keypad. Windows XP, 2000 or 98 compatible.	Subscription service options: $249/year for weather. Unlimited access to graphics and text. 2km resolution for level NEXRAD mosaics. Charges per min apply as per Aircell arrangement. Other options include New data and FlightMap updates ranging from $495/year (28 day updates), $229 for every 56 days, $149 for every 3 months, or $99 for 1x a year update.	Merlin service available mid 2002. AirCell current.	DTC and Dynacorp DUATs. Worldwide weather available via Jeppesen International Weather Service.	Cellular solution via AirCell (current) and GEO solution via Merlin (planned)	Need the aircell phone	30 day on S/W.	All aircraft applicable.	Looking to display products on other vendor MFD's. Plans TBD. No current certification issues as laptop is portable.
55 Inverness Drive east, Englewood, CO 80112-5498	303 328 4779										
0026 0000 0000 1001	rowe.matthew@jeppesen.com										

REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

1. AGENCY USE ONLY (*Leave blank*)	2. REPORT DATE	3. REPORT TYPE AND DATES COVERED
	October 2002	Final Contractor Report

4. TITLE AND SUBTITLE

NASA Aviation Safety Program Weather Accident Prevention/Weather Information Communications (WINCOMM)

5. FUNDING NUMBERS

WU–728–40–20–00
C–77109–T

6. AUTHOR(S)

Arthur Feinberg and James Tauss

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)

Aviation Management Associates, Inc.
8752 Center Road
Springfield, Virginia 22152

8. PERFORMING ORGANIZATION REPORT NUMBER

E–13593

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)

National Aeronautics and Space Administration
Washington, DC 20546–0001

10. SPONSORING/MONITORING AGENCY REPORT NUMBER

NASA CR—2002-211903

11. SUPPLEMENTARY NOTES

Project Manager, Gerald Chomos, Communications Technology Division, NASA Glenn Research Center, organization code 5640, 216–433–3485.

12a. DISTRIBUTION/AVAILABILITY STATEMENT

Unclassified - Unlimited
Subject Category: 32 Distribution: Nonstandard

Available electronically at http://gltrs.grc.nasa.gov

This publication is available from the NASA Center for AeroSpace Information, 301–621–0390.

12b. DISTRIBUTION CODE

13. ABSTRACT ***(Maximum 200 words)***

Weather is a contributing factor in approximately 25-30 percent of general aviation accidents. The lack of timely, accurate and usable weather information to the general aviation pilot in the cockpit to enhance pilot situational awareness and improve pilot judgment remains a major impediment to improving aviation safety. NASA Glenn Research Center commissioned this 120 day weather datalink market survey to assess the technologies, infrastructure, products, and services of commercial avionics systems being marketed to the general aviation community to address these longstanding safety concerns. A market survey of companies providing or proposing to provide graphical weather information to the general aviation cockpit was conducted. Fifteen commercial companies were surveyed. These systems are characterized and evaluated in this report by availability, end-user pricing/cost, system constraints/limits and technical specifications. An analysis of market survey results and an evaluation of product offerings were made. In addition, recommendations to NASA for additional research and technology development investment have been made as a result of this survey to accelerate deployment of cockpit weather information systems for enhancing aviation safety.

14. SUBJECT TERMS

Data links; Market research

15. NUMBER OF PAGES

63

16. PRICE CODE

17. SECURITY CLASSIFICATION OF REPORT	18. SECURITY CLASSIFICATION OF THIS PAGE	19. SECURITY CLASSIFICATION OF ABSTRACT	20. LIMITATION OF ABSTRACT
Unclassified	Unclassified	Unclassified	